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REPORT #
RRTAC 93-1

Reclamation of Native Grasslands in Alberta: A Review of the Literature

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Heritage Fund

Alberta
LAND CONSERVATION AND
RECLAMATION COUNCIL
Reclamation Research
Technical Advisory Committee

Alberta's Reclamation Research Program

Regulating surface disturbances in Alberta is the responsibility of the Land Conservation and Reclamation Council. The Council Chairman is from Alberta Environmental Protection. The Council oversees a reclamation research program, established in 1978, to identify the most efficient methods for achieving acceptable reclamation in the province. Funding for the research program is provided by Alberta's Heritage Savings Trust Fund, Land Reclamation Program.

To assist with the development and administration of the research program, the Council appointed the inter-departmental Reclamation Research Technical Advisory Committee (RRTAC). The Committee consists of eight members representing the Alberta Departments of Agriculture and Rural Development, Energy, and Environmental Protection, and the Alberta Research Council. The Committee updates research priorities, reviews research proposals, organizes workshops, and otherwise acts as the coordinating body for reclamation research in Alberta.

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REPORT #
RRTAC 93-1

Reclamation of Native Grasslands in Alberta: A Review of the Literature

by

D.S. Kerr, L.J. Morrison and K.E. Wilkinson

Environmental Management Associates

Calgary, Alberta

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Prepared for

ALBERTA LAND CONSERVATION AND RECLAMATION COUNCIL
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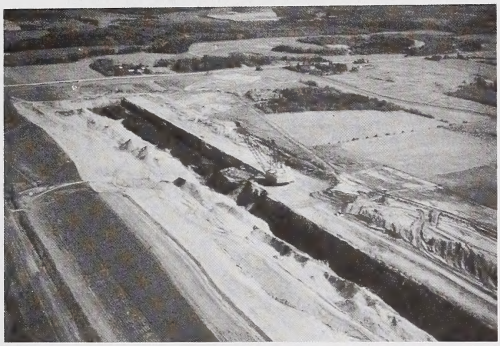

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DISCLAIMER

This report is intended to provide government and industry staff with up-to-date technical information to assist in the preparation and review ofConservation and Reclamation Approvals, and development of guidelines and operating procedures. This report is also available to the public so that interested individuals similarly have access to the most current information on land reclamation topics.

The opinions, findings, conclusions, and recommendations expressed in this report are those of the authors and do not necessarily reflect the views of government or industry. Mention of trade names or commercial products does not constitute endorsement, or recommendation for use, by government or industry.

Chairman's Note: Just prior to this report going to press I came across a new publication titled Ecosystem Rehabilitation, Volume 2: Ecosystem Analysis and Synthesis edited by M.K. Wali and published by SPB Academic Publishing bv, The Hague, The Netherlands. There is a chapter entitled Grassland Rehabilitation after Coal and Mineral Extraction in the Western United States and Canada by L.R. Iverson and M.K. Wali. I would strongly suggest that you obtain a copy of their article to complement this report.

REVIEWS

This report was reviewed by members of RRTAC.

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ABSTRACT

A review of the literature on native grassland reclamation was conducted to summarize the current status of knowledge on reclamation and restoration efforts within Alberta. The nature and scope of the review is comprehensive, including an overview of the regulations and guidelines governing land use on native prairie; a description of the dominant grassland ecoregions in Alberta; a review of the common disturbance types, extent and biophysical effects of disturbance on native prairie within Alberta; a description of the factors which influence the degree of disturbance and reclamation; and examples of both natural and enhanced recovery of disturbed sites through the examination of selected case studies. The literature review serves as the basis for future examination of specific native grassland reclamation and restoration topics where information is currently lacking or is not well documented. Literature sources were complemented by discussions and information supplied from both government and non-government agency personnel as well as from private companies and individuals.

Conclusions from the literature review indicate that while reclamation of native grasslands has developed considerably in terms of techniques and methods over the last twenty years much of the information is not well documented in the scientific literature. This is particularly true where restoration efforts have been attempted. The problems and technical difficulties associated with re-creating a functioning native prairie from one that has been disturbed are exacerbated by the lack of long term, comparative field monitoring data and analysis within the grassland ecoregions of Alberta, or indeed elsewhere in North America. The complexity and community dynamics of the native prairie ecosystem requires further research to provide the basis for more applied investigation of such topics as native seed selection, seedbed preparation, seeding rates and other revegetation techniques such as seeding methods or sodding.

The literature review also identified the need for a more integrated approach in vegetation and soil research with respect to native prairie reclamation and restoration. As more research is conducted, reclamation requirements will reflect our expanded knowledge base. As an example, preliminary investigations indicate that reclamation requirements specifying the stripping of topsoil prior to construction activities (such as pipelines) may be inappropriate under certain conditions where the objective of reclamation is to limit the effect on native vegetation productivity. Natural revegetation by native species may be more effective under certain conditions where disruption of the soil is minimized.

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1. INTRODUCTION

1.1 BACKGROUND

Land use changes affecting the nature and distribution of natural grassland ecosystems have long been recognized as a consequence of agricultural, industrial and commercial development. Within Canada, the degree and extent of such changes to the native prairie grassland ecosystem has been described as follows:

> "Within one human lifetime, the prairies have passed from wilderness to become the most altered habitat in Canada and one of the most disturbed, ecologically simplified and overexploited regions of the world."
>
> (Dr. Adrian Forsyth, Endangered Spaces, The Future for Canada's Wilderness).

The loss of both floral and faunal species diversity is compounded by simplification of the genetic pool with significant ramifications for future use of native grassland biological resources.

Given the dramatic alteration in prairie grassland ecosystems which has occurred over the last sixty to one hundred years, an increasing emphasis is now being placed on native prairie reclamation through a variety of revegetation methods and techniques. However, despite the considerable advances which have been made in the reclamation of disturbed lands, our basic understanding of reclamation processes specifically within native grassland ecosystems remains poorly defined. The Reclamation Research Technical Advisory Committee (RRTAC) has commissioned the following study to compile the available existing information on the status of native grassland reclamation within Alberta.

Prairie reclamation can occur on many scales, ranging in scope from individual residential developments to oil well drilling leases to large scale, open-cast mining operations. The objectives of the following report were to summarize the current status of native grassland reclamation within Alberta, including a review of the regulations and guidelines affecting reclamation, a description and analysis of the biophysical setting of the major grassland ecoregions within Alberta and an assessment of the factors which influence the degree of disturbance and subsequent reclamation success. Selected case study examples are used to demonstrate the various techniques and methods which are currently being used while also providing an appreciation of the challenges involved in successful conservation of the fragile native prairie ecosystem.

1.2 DEFINITION OF TERMINOLOGY

A variety of reclamation terminology is currently in use relating to both soil and vegetation parameters. In order to ensure a common understanding of these terms within the context of native grassland reclamation and restoration, the terms used in this report are described on the basis of the definitions generally used by the Reclamation Research Technical Advisory Committee (RRTAC) as follows:

Reclamation

The process of returning disturbed land to its former or other productive uses. All practicable and reasonable methods of designing and conducting an activity to ensure:

(1) stable, non-hazardous, non erodible, favourably drained soil conditions, and

(2) equivalent land capability

Land Capability

The suitability of land for use without permanent damage. It is an expression of the effect of physical land conditions, including climate, on the total suitability for use, without damage, for crops that require regular tillage, for grazing, for woodland and for wildlife. Land capability involves consideration of the risks of land damage from erosion and other causes and the difficulties in land evaluation owing to physical land characteristics, including climate.

Equivalent Land Capability

The ability of the land to support various land uses after reclamation is similar to the ability that existed prior to an activity being conducted on or affecting the land. The ability of the land to support an identical land use, both before disturbance and after reclamation, is not necessarily required.

Rehabilitation

Implies that the land will be returned to a form and productivity in conformity with a prior land use plan, including a stable ecological state that does not contribute substantially to environmental deterioration and is consistent with surrounding aesthetic values.

Restoration

The process of restoring site condition as they were before the land disturbance.

Revegetation

The establishment of vegetation which replaces original ground cover following land disturbance.

Native Species

A species that is a part of an area's original fauna or flora.

Native Prairie

An area of unbroken grassland or parkland dominated by non-introduced species.

Natural Revegetation

Natural re-establishment of plants; propagation of new plants over an area by natural processes.

2. OBJECTIVES OF THE REVIEW

The objective of this study was to prepare a comprehensive literature review on the subject of native grassland reclamation and restoration within Alberta. The approach involved documenting the biophysical and cultural factors which influence the type and degree of disturbance within a biophysical (ecoregion) context. This involved describing the existing legislation applicable to native grassland reclamation and restoration and an evaluation of the various techniques and methods which are currently being used, both in a general and site-specific sense. A review of selected case studies was also conducted in order to include specific examples of the type of reclamation and restoration efforts currently being employed within Alberta.

Specific objectives of the review included the following:

1. Define the appropriate soil and vegetation parameters pertaining to native grassland reclamation.
2. Review the existing and proposed regulations and guidelines applicable to native grassland reclamation and restoration and examine the objectives, implementation and results of such legislation.
3. Describe the biophysical (climate, landform, soil and vegetation) conditions of the dominant grassland ecoregions within Alberta and determine the type and degree of disturbance which occurs within each ecoregion.
4. Describe the factors which determine the degree of disturbance and influence the success of reclamation and restoration on native grasslands within Alberta.
5. Document examples of natural and enhanced recovery of disturbed native grasslands through a review of selected case studies.
6. Prepare a summary of the report findings and provide recommendations on further utilization of native grassland reclamation and restoration techniques and methods within Alberta.

3. REGULATIONS AND GUIDELINES GOVERNING LAND USE ON NATIVE PRAIRIE

3.1 BACKGROUND

There are few, if any, regulations or guidelines developed at a provincial or federal level which specifically identify or address native grassland in a protection or reclamation sense. The specific issue of the restoration of native grasslands is not discussed by the legislation. However, a number of regulations and guidelines are broad enough in scope such that the protection or reclamation of native grasslands may be included.

The impetus for increasingly stringent reclamation requirements continues to be expressed in the form of guidelines and practises of the various government agencies which administer these Acts. Reclamation is seen increasingly as more than a means to control erosion but rather as an opportunity to provide for the more intrinsic benefits of native grassland rehabilitation with one objective being native grassland restoration. Many of the government agencies who contributed information to this study expressed a clear commitment to expanding the regulatory requirements of native grassland reclamation through the development of a variety of integrated directives, guidelines and practises. The 1993 Alberta Environmental Protection and Enhancement Act and the creation of the new Department of Environmental Protection will hopefully provide an opportunity to continue these initiatives.

3.2 ALBERTA

3.2.1 Present Status

The protection of native grasslands within Alberta, at present, lies chiefly in controls on development as administered through Alberta Environment, and Alberta Forestry, Lands and Wildlife. These two Departments, along with the Parks Division of Alberta Tourism, Parks and Recreation, were combined to form the new Alberta Environmental Protection Department. Although no legislation exists which specifically addresses the reclamation and restoration of native grasslands, a number of Acts and Regulations may be applied to this issue. The principle governing acts, and the respective governing bodies are outlined in Figure 1. A brief summary of the regulations and guidelines considered relevant to the protection or reclamation of native grasslands within Alberta is provided in the following sections.

3.2.1.1 Petroleum Activity on Native Prairie - Guidelines for Surface Disturbances. Some of the most extensive natural grasslands remaining in Alberta are found within the area administered by the Special Areas Board. As a result of coordination between the Special Areas Board,

ALBERTA ENVIRONMENT

- Land Surface Conservation & Reclamation Act
- Dept. of Environment Act
- Environment Council Act
- Agricultural Chemicals Act
- Alberta Natural Resources Act

ALBERTA FORESTRY, LANDS & WILDLIFE

PUBLIC LANDS DIVISION

FISH & WILDLIFE DIVISION

ALBERTA FOREST SERVICE

- Dept. of Forestry, Lands & Wildlife Act
- Public Lands Act
- Forest & Prairie Protection Act
- Crown Cultivation Leases Act
- Land Surface Conservation & Reclamation Act
- Wildlife Act
- Wilderness Areas, Ecological Reserves & Natural Areas Act

ALBERTA MUNICIPAL AFFAIRS

- Special Areas Act
- Planning Act

ALBERTA AGRICULTURE

- Agricultural Development Act
- Surface Rights Act
- Soil Conservation Act
- Irrigation Act
- Agricultural Pests Act
- Weed Control Act

ERCB

- Energy Resources Conservation Act
- Pipelines Act

TRANSPORTATION & UTILITIES

- Public Highways Development Act

ALBERTA TOURISM, PARKS & RECREATION

- Dept. of Recreation & Parks Act
- Provincial Parks Act
- Wilderness Areas, Ecological Reserves & Natural Areas Act
- Recreation Development Act
- Recreation, Parks & Wildlife Foundation Act

Figure 1. Provincial Agencies Involved in the Management and/or Administration of Native Grasslands.

the Energy Resources Conservation Board (ERCB), Alberta Environment, Alberta Forestry, Lands and Wildlife (AFLW), and Alberta Energy a document titled "Petroleum Activity on Native Prairie - Guidelines for Surface Disturbances" has been developed.

The guidelines in the document apply to the petroleum and natural gas industries, including exploration, development and production activities on native prairie within a designated core area outlined in the document (Special Areas Board et al. 1992). The core area approximates the extent of the mixed and fescue grassland ecoregions in Alberta (see Section 4.0) but it is intended that the guidelines also be applied to grasslands in the aspen parkland ecoregion. The principle of minimizing the extent of surface disturbance on native prairie is the goal of the guidelines. The primary issue is the need for action to ensure native prairie areas are not permanently destroyed or altered by unnecessary impacts resulting from petroleum and natural gas activities. Accordingly, the guideline specifically recognizes the following:

1. due to the highly sensitive nature of the native grassland ecosystems, and their presence largely in semi-arid and arid climates, any disturbance should be minimized due to the difficulty in re-establishing native species. The benefits of minimal disturbance should be reflected in reduced construction and reclamation costs as well as reduced erosion.
2. existing provincial guidelines for reclamation and soil management have limited applicability for prairie environments. Standard soil stripping practices do not work in many difficult soil conditions in native prairie grasslands because of the difficulty in re-establishing native vegetation.
3. there is a need for industry to consider a longer time period in the development of an oil or gas field. In certain areas there has been extensive infilling development which has caused unnecessary impacts to native grasslands which may have been reduced if development planning had been more comprehensive.

3.2.1.2 Energy Resources Conservation Act. The ERCB is charged with energy resource and environment management functions with regards to oil, gas, oil sands, pipelines, hydro and electric energy, and coal. These functions are administered under Alberta's 1971 Energy Resources Conservation Act. The ERCB's development branch is responsible for all oil and gas field operations and for enforcing the Board's pollution control regulations. With respect to native grasslands, general guidelines have been developed as a result of cooperation between the Special Areas Board, ERCB, Alberta Environment, Alberta Forestry, Lands and Wildlife, and Alberta Energy.

These guidelines have been previously discussed (Section 3.2.1.1).

3.2.1.3 Department of the Environment Act. The Department of Environment is responsible for the coordination of the policies, programs and services of departments within the provincial government and of government agencies in matters pertaining to the environment. The Act sets out the operation, function and administration of the Provincial Department of the Environment and is administered by the Natural Resources Coordinating Council and the Conservation Utilization Committee. Under the terms of this Act the following matters may be applicable to native grasslands:

1. the conservation, management and utilization of natural resources;
2. the prevention and control of pollution of natural resources;
3. any operations or activities that adversely affect or are likely to adversely affect the quality or quantity of any natural resource;
4. any operations or activities that destroy, disturb, pollute or alter a natural resource, or are likely to do so; and,
5. the preservation of natural resources for their aesthetic value.

Through regulations formulated under this Act, any part of Alberta may be established as a "Restricted Development Area", thereby protecting the area from degradation or preserving its natural condition. This condition may have implications for the protection of native grasslands in Alberta.

3.2.1.4 Environment Council Act. The Environment Council of Alberta's function is to conduct a continuing review of policies and programs of government agencies on matters pertaining to environment conservation at the request of the Minister of Environment. The Council has no administrative or approval authority; it is sometimes required to conduct inquiries into alleged contraventions of environment protection legislation.

3.2.1.5 Land Surface Conservation and Reclamation Act. The Land Surface Conservation and Reclamation Act is administered jointly by Alberta Environment and Alberta Forestry, Lands and Wildlife, through the Land Conservation and Reclamation Council (LCRC). The Council is a joint committee made up of members from Alberta Environment and Alberta Forestry, Lands and Wildlife, chaired by the Alberta Environment representative. The Act generally applies to all land within Alberta except for land used or intended for residential use or any agricultural operation. Although no specific guidelines for native grasslands are outlined, there is considerable opportunity for the regulating agencies to specify protection or reclamation requirements where developments impact native grasslands through regulated activities. Surface disturbance means the disturbance, exposure, covering or

erosion of, or the contamination, degradation or deterioration of the surface of the land in any matter. The LCRC processes applications for development and reclamation approval and issues reclamation orders and certificates for regulated developments. An applicant must submit comprehensive plans detailing the proposed methods of development and reclamation.

With respect to non-regulated developments the Act provides guidelines for reclamation and the Council acts to ensure proper reclamation is conducted.

The Act pertains most specifically to regulated surface operations although it also has implications for other activities which may affect the quality of the natural environment. Pursuant to Section 23 of the Act any kind of operation or activity may be designated as a regulated surface operation if the operation or activity falls within the following general categories:

1. the drilling, operation or abandonment of a well;
2. the construction, operation or abandonment of a pipeline, battery, transmission or telecommunication line, manufacturing or processing plant (for minerals, gravels, petroleum, chemicals, pulp and paper, fertilizers, etc.), thermal electrical generation station, road, railway or aircraft landing strip;
3. the opening up, operation or abandonment of a mine, quarry or pit, or of a waste disposal site or landfill;
4. exploration operations that result or will result in surface disturbance;
5. the conduct of examinations and surveys on land made in connection with surface and subsurface water, and the construction of any works for the impoundment, conveying or diversion of water;
6. the preparation of land to be used for the purpose of industrial sites or for recreational development;
7. the excavation and removal of topsoil or peat for sale;
8. the excavation and removal of archaeological findings; and,
9. any alterations of or extensions to any operation or activity referred to above;
10. the construction, operation or abandonment of any structure (including a micro-wave tower) forming part of a broadcasting undertaking as defined in the *Broadcasting Act* (Canada);
11. the construction, operation or abandonment of a site for subsurface disposal of solid or liquid waste.

Under this Act, reclamation orders and certificates may be issued for lands, including

native grasslands, which are, have been, or may be connected to the aforementioned disturbances. Lands located off the disturbance site may also be subject to the conditions of the Act if such lands have been impacted as a result of the activities occurring within the designated disturbance area, such as when a spill occurs.

The terms and conditions of the Act do not apply to any agricultural operation or activity, including grazing, and such operations or activities may not be designated as regulated surface operations.

Although the Act does not pertain specifically to the reclamation of native grasslands, a significant proportion of its content is applicable to that setting. Under the terms of this Act, regulations may be developed which exclude any type of development on any lands in Alberta. Furthermore, the regulations may prescribe the circumstances and manner in which any class of lands must be maintained and reclaimed. All maintenance and reclamation of surface lands must occur in accordance with the regulations. This act will be superseded by the Alberta Environmental Protection and Enhancement Act in 1993.

3.2.1.6 Public Lands Act. This Act provides for the management and administration of all provincial public lands with the exception of those occurring in the Special Areas. Those areas outside the Special Areas are administered by Public Lands Division, Alberta Forestry, Lands and Wildlife (AFLW). Under the provisions set out in various sections of the Act such as Section 10, public land is managed for many uses. Under Sections 51, 60 and 61 direction is given on environmental matters. However, the Minister of Forestry, Lands and Wildlife is given the right under Section 19 (3) to set terms and conditions for any disposition. With every disposition on public land, conditions form part of the lease agreement. The majority of these conditions involve environmental protection.

Part 4 of the Public Lands Act deals specifically with grazing leases. Under the terms and conditions of the Act, public lands may be leased for terms not exceeding 20 years for the purpose of grazing livestock when the Minister of Forestry, Lands and Wildlife deems grazing to be the best use of the land. At present, an area sufficient to graze 600 head of cattle may be designated under a grazing lease, unless such an area would adversely affect the interests of farmers or ranchers residing in the vicinity of the leased land. There are no specific constraints outlined with respect to the effects of grazing lease size or use on the environment. However, some applications of this Act to the protection of native grasslands may be possible.

Pursuant to the Act, the Minister may establish the grazing capacity of all grazing land in Alberta and for this purpose may divide the province into grazing districts, establish the grazing capacity of land within each district and may establish the grazing capacity of land held under a grazing lease either above or below the grazing capacity of other grazing land in the district. Unless specified for an area, the grazing capacity of the land is the same as that specified for the grazing district.

Under the Act, regulations may be made which:

1. govern the applications for grazing leases and the eligibility of applicants for grazing leases;
2. prescribe the rights and obligations of grazing lessees in relation to the use and occupation of the land held under a grazing lease;
3. prescribe the terms and conditions on which grazing lessees may conduct range improvement projects on the land contained in their grazing leases;
4. prescribe the circumstances under which the Minister may refuse to consent to an assignment of a grazing lease and govern any other matter relating to the assignment of grazing leases; and,
5. generally provide for any other matter pertaining to grazing leases, grazing lessees or other issues.

Pursuant to the public grazing lands range improvement regulation, the government may provide financial assistance to facilitate a public grazing lands improvement program. This program may involve:

1. clearing, breaking, working down and seeding of brush covered lands and other low productivity lands to tame forage species;
2. constructing cross-fences, water facilities, trails and other works to enhance range utilization; and,
3. spraying, burning, mowing, fertilizing or other control or enhancement measures to maintain the range and to control brush encroachment.

3.2.1.7 Special Areas Act. This Act provides for setting boundaries of Special Areas, disposition (including leasing) of all public lands within the Special Areas and setting aside lands for community purposes. The Act is administered by Alberta Municipal Affairs.

3.2.1.8 Soil Conservation Act. Pursuant to the Act, it is the responsibility of all landowners to take those measures appropriate to prevent soil loss or deterioration from taking place on their property and, if such is taking place, to stop the loss or deterioration from continuing. This Act does not apply to any operation or activity governed by the Land Surface Conservation and Reclamation Act. Under the Act, the local government has the power to insist that appropriate measures be undertaken to promote soil conservation. Under the terms of this Act, regulations for permits may be issued for the removal of topsoil from the land and the burning of stubble on the land. The implication for disturbances of native grasslands may be that sufficient management practices must be implemented to ensure soil loss or deterioration does not occur as a result of the disturbance.

3.2.1.9 Wilderness Areas, Ecological Reserves and Natural Areas Act. This act is jointly administered by AFLW and Alberta Tourism, Parks and Recreation. It is used to designate wilderness areas, ecological reserves and natural areas within the Province. Accordingly, the terms and conditions of this Act may be directly applicable to the reclamation of native grasslands in Alberta, where such lands correspond to the aforementioned areas.

Under this Act, ecological reserves are established to preserve public lands for ecological purposes. Typically, these areas have scientific value, are representative of a natural ecosystem in Alberta, contain rare or endangered native plants or animals that should be preserved, or contain unique or rare examples of natural biological or physical features. Natural areas may be established to protect sensitive or scenic public land from disturbance and to ensure the availability of public land in a natural state for use by the public for recreation, education or any other purpose. Prohibited activities within Ecological Reserves and Wilderness Areas include: travel by motor vehicle (including boats) or horse; hunting, trapping or fishing; landing an aircraft; depositing any waste materials except in areas designated for such activity; unless otherwise authorized, collecting, destroying or removing any plant or animal life, excavating or removing fossils or other objects of geological, ethnological, historical or scientific interest; introducing any material or substance that is or may be harmful to plant or animal life; lighting or maintaining an open fire; or otherwise altering the reserve or area.

Given the limited extent of native grasslands in Alberta some areas may in the future be designated as wilderness areas, ecological reserve or natural area and, as such, these areas may qualify for protection or reclamation requirements under this Act.

3.2.1.10 Forest and Prairie Protection Act. This Act deals primarily with the protection and management of forested areas and is administered by the Alberta Forest Service. Under the Act, the Minister of Forestry, Lands and Wildlife may authorize any steps deemed necessary for the clean-up operations necessitated by pollution from oil or gas or other surface disturbance operations. The use of all personnel and equipment may be ordered to contain or clean-up pollution or for fire fighting. The Act is applicable to native grasslands as well as other areas in the province.

3.2.1.11 Natural Resources Conservation Board Act. A recent development in natural areas protection has been the establishment of the Natural Resources Conservation Board Act. The purpose of this Act is to provide for an impartial process to review projects that will or may affect the natural resources (other than energy) of Alberta. Under the Act, this review will determine whether the project is in the best interest of the public, with regard to the social and economic effects of the project and the effect of the project on the environment. Regulations may be made to govern any aspect of this Act. A significant amount of leverage with respect to protecting native grass-

lands and reclaiming native grasslands may be generated through this Act.

3.2.1.12 Alberta Environmental Protection and Enhancement Act (Draft). The Alberta Environmental Protection and Enhancement Act (AEPEA) provides an opportunity to develop a more streamlined process of environmental protection. Passed only recently, in 1992, the full implications of the Act have not yet been assessed. Briefly, nine existing acts are incorporated into the Act, providing effective and integrated environmental legislation for Alberta. The Act is likely to have implications for the reclamation of native grasslands in Alberta, including:

1. environmental impact assessments and approvals;
2. contaminant release;
3. conservation and reclamation;
4. waste management;
5. hazardous substances, pesticides and other agricultural chemicals; and,
6. unlawful, unauthorized and accidental releases.

Under the conditions of the Act, environmental protection orders may be issued requiring the protection or restoration of the environment of any designated area in the province. Further, the manner or method of this activity may be specified. If applied to native grassland areas, this portion of the Act allows the nature and extent of reclamation efforts to be specified by the Minister of Environment.

Under the environmental impact assessment (EIA) portion of the Act, environmental impact assessment is defined as the identification and analysis of the potential positive and negative impacts of a proposed project, including an analysis of the significance of those impacts and a determination of the acceptability of the proposed project. Accordingly, it allows for the implementation of regulations which could be applied specifically towards native grassland protection, reclamation or restoration.

Under the conservation and reclamation portion of this Act, an operator of any disturbance is required to reclaim specified lands in accordance with the specific terms and conditions of the development approval, including any environmental protection order or reclamation order, the directions of an inspector or the conditions of this Act or its regulations. A reclamation certificate is required subsequent to such work being conducted and approved. While not directly dealing with native grasslands, this portion of the Act provides the opportunity for specific reclamation efforts to be required in native grassland areas. Furthermore, this portion of the Act allows for the protection or reclamation of lands located off the development site.

Pursuant to this Act it is necessary for remedial or reclamation efforts to be implemented where an accidental release of a hazardous substance, pesticide or contaminant has occurred into the environment. While not specifically dealing with native grassland areas this portion of the Act requires that an accidental release in an area of native grassland must be cleaned up

and the affected area be restored to an acceptable condition.

3.2.1.13 The Prairie Conservation Coordinating Committee. The Prairie Conservation Coordinating Committee was established by the Government of Alberta in 1989 in conjunction with the World Wildlife Fund. Under this committee, a Prairie Conservation Action Plan (PCAP) was produced which set forth a five-year action plan aimed at prairie-wide efforts to conserve and manage native prairie and parkland species, communities and habitats. The PCAP was produced by a steering committee comprising representatives from government and non-government organizations in each of the prairie provinces.

The PCAP lists 10 goals and makes numerous recommendations for specific action. The goals are:

1. Identify the remaining native prairie and parkland;
2. Protect at least one large, representative area in each of the four major prairie ecosystems (Mixed Prairie, Tall Grass Prairie, Fescue Prairie and Aspen Parkland);
3. Establish a system of protected native prairie ecosystems across the three prairie provinces and, where possible, create connecting corridors. This system should include representative samples of each habitat subregion;
4. Protect threatened ecosystems and habitats by preparing and implementing habitat management and restoration plans;
5. Protect and enhance the populations of prairie species designated nationally or provincially as vulnerable, threatened or endangered by implementing recovery and management plans;
6. Ensure that no additional species become threatened, endangered or extirpated;
7. Encourage governments to incorporate conservation of native prairie more explicitly in their programs;
8. Encourage balanced use of private lands that allows sustained use of the land while maintaining and enhancing the native biological diversity of the prairies;
9. Promote public awareness of the values and importance of prairie wildlife and wild places; and
10. Promote research relevant to prairie conservation.

Other initiatives, such as the Prairie Farm Rehabilitation Administration (PFRA) to reduce the overuse of marginal agricultural lands, and the Permanent Cover Program (Marciak 1992 pers. comm.), provide additional regulations and guidelines in the management of prairie grasslands across the prairie provinces. Another important initiative is the North American

Waterfowl Management Plan (NAWMP) which concentrates efforts to protect wetlands and associated uplands for waterfowl. The NAWMP is sponsored by governments as well as nongovernment agencies such as Ducks Unlimited and Wildlife Habitat Canada.

3.3 SASKATCHEWAN

3.3.1 Present Status

As is the case in Alberta, protection, reclamation or restoration of disturbance within Saskatchewan's native grasslands is not governed by a specific guideline or legislation. However, a number of guidelines, Acts and Regulations have implications for controlling land use within areas of native prairie. Generally, Saskatchewan Environment is responsible for ensuring that areas of native grassland are protected and reclaimed in an appropriate manner. The principle governing acts controlling land use on native prairie habitats within Saskatchewan include the following:

1. Ecological Reserves Act;
2. Environmental Assessment Act;
3. Environmental Management and Protection Act;
4. Parks Act;
5. Surface Rights and Compensation Act;
6. The Critical Wildlife Habitat Protection Act; and,
7. The Conservation and Development Act.

In addition to these Acts, a number of guidelines have been developed to direct the protection, development and reclamation, or restoration of environmentally sensitive or natural areas within Saskatchewan. While not specifically dedicated to native grasslands, their use is generally related to such areas. These include:

1. Guidelines for Oil and Gas Development on Environmentally Sensitive Lands in Southern Saskatchewan;
2. Guidelines for Sensitive Terrain in Southern Saskatchewan;
3. Guidelines for Conducting Seismic Exploration on Environmentally Sensitive Lands in Southern Saskatchewan;
4. Guidelines for the Reclamation of Sensitive Terrain in Southern Saskatchewan; and,
5. An Evaluation of Reclamation Potential and Techniques for Environmentally Sensitive Areas in Southwestern Saskatchewan.

A brief summary of the Acts and guidelines as they relate to prairie grassland protection and reclamation follows.

3.3.1.1 Ecological Reserves Act. Under the Act, ecological reserve includes any Crown land in the province designated as such and which sustains or is associated with unique or representative parts of the natural environment. The protection of native grasslands and the reclamation of native grasslands are two issues which have considerable attention under the terms and conditions of this Act. The Act describes the circumstances and

conditions under which an ecological reserve may be entered and the activities which may be conducted there and, further, the Act may specify the manner in which such activities must protect or reclaim affected lands.

3.3.1.2 Environment Assessment Act. This Act governs the licensing, permitting, approval or consent for any development which may affect any unique, rare or endangered feature of the environment, which may cause pollution or which may cause public concern because of potential environmental changes. Accordingly, an environmental impact assessment (EIA) may be required prior to the permitting of any development. The protection of native grasslands and the reclamation of native grasslands may be principle targets for protection or the implementation of specific reclamation measures under the terms and conditions of this Act.

Environmentally sensitive areas (ESA's) in Saskatchewan are protected under this Act. Saskatchewan Environment, the governing body of this Act, has identified specific Crown range lands as environmentally sensitive. ESA's in Saskatchewan are typically characterized as native range lands in regions of low rainfall and high evaporative potential. Typically, vegetation is sparse, soils have low fertility and poorly developed topsoil, and terrain consists of steep sloping valleys, escarpments, coulees, badlands, hill complexes or extensive sand flats and dunes. Once disturbed, these lands are difficult to reclaim. Oil and gas developments are screened for Environmental Impact Assessment requirements prior to project initiation. Often an environmental protection plan (EPP) is required.

3.3.1.3 Environmental Management and Protection Act. Under this Act, the Minister of the Environment is granted general powers in relation to environmental issues and has access to land to investigate and deal with environmental concerns. The Minister is granted broad powers with respect to the discharge of pollutants into the environment and may request the clean-up and/or restoration of an area following such a discharge. Permits must be obtained from the Minister for any development which may impact the environment. The Minister may specify the manner, method or procedures to be used in carrying out the measures required by an order and the time within which any measure shall be commenced and completed. Although the Act does not specify activities relative to native grasslands there are implications for the protection and reclamation of such areas.

3.3.1.4 Parks Act. This Act governs the establishment, maintenance and use of park land and park land reserves in Saskatchewan. Under the Act the natural, prehistoric and historic resources of park lands in Saskatchewan are to be maintained for the benefit of future generations. Furthermore, protected areas should be used primarily for the protection and preservation of their natural, prehistoric or historic resources of interest or significance. Those areas of the province governed specifically by the Act are outlined in the Act. The premise of this Act has significant

implications for reclamation of native grasslands in a manner compatible with the pre-disturbance condition.

3.3.1.5 Surface Rights Acquisition and Compensation Act. Land surface requirements for petroleum activity requires access onto either public or private lands, achieved by negotiation and mutual agreement, right of entry or expropriation. This Act provides a comprehensive procedure for acquiring surface rights, ensures the payment of just and equitable compensation and provides for the maintenance and reclamation of the surface of the land acquired under the Act. Compensation may be required where disturbance to the land may cause inconvenience or decrease the value of the land for its original purpose (i.e., agriculture production or native grassland). Through a mutual agreement or arbitration, environmental issues are discussed, guidelines or controls are outlined and compensation/mitigation is provided.

3.3.1.6 The Critical Wildlife Habitat Protection Act. This Act outlines those lands which are protected under the Act and it allows for the development of specific regulations whereby other lands may be designated as critical wildlife habitat. All critical wildlife habitat lands are to be managed and used in the manner prescribed in the regulations. Often critical wildlife habitat areas correspond to areas of native grasslands and, in these cases, the native grasslands must be protected or reclaimed in a manner consistent with any specifications made under the Act.

Under the terms and conditions of the Act, alterations to critical wildlife habitat lands are prohibited unless specifically authorized by the Minister of Parks and Renewable Resources. The implication of this stipulation is that native grasslands are often subject to stringent protection and reclamation guidelines when they are designated as critical wildlife habitat.

3.3.1.7 The Conservation and Development Act. Pursuant to the Act the Minister of Parks and Renewable Resources may establish conservation and development areas if, in his opinion, land therein can be benefitted by means to save, conserve or develop any land or any water resource. This has implications for native grassland areas if they become protected under this Act. Once established as a conservation and development area, specific protection or reclamation requirements may be made.

The guidelines previously listed have a number of common themes with respect to reclamation of native grassland areas. Generally the key concepts addressed include project planning, access, site selection, drilling, flowlines and cleanup activities on Crown-held lands. The focus of the guidelines are to protect fragile environments, areas which frequently correspond to native grasslands in southern Saskatchewan. The guidelines outline the use of an environmental protection plan (EPP) which describes the local environment (terrain, soils, vegetation and wildlife) and which outlines the reclamation activities as a means by which impacts may be avoided or mitigated. In some instances a more comprehen-

sive impact assessment (EIA) will be required. The concept of site planning to ensure minimal disturbance occurs in sensitive areas is promoted (i.e., minimal grading, use existing access, etc). Under the terms of the guidelines reclamation following disturbance should stabilize the area and restore it as closely as possible to its pre-disturbance state. Revegetation using native grasses is encouraged for reclamation of native grasslands. Wind and water erosion must be controlled to allow for successful revegetation.

3.3.3.8 Guidelines for Oil and Gas Development on Environmentally Sensitive Lands in Southern Saskatchewan. In these guidelines Saskatchewan Environment recommends procedures which should be followed during oil and gas development on environmentally sensitive lands in southern Saskatchewan. The guidelines address most aspects of smaller-scale oil and gas projects, including project planning, access, site selection, drilling, flowlines and clean-up. The guidelines are a practical approach to protection of fragile terrain. Typically this terrain corresponds to areas of native grassland vegetation, characterized by low rainfall, high evapotranspiration and relatively infertile soil conditions. Often these lands are used as rangelands.

Oil and gas development within environmentally sensitive lands in southern Saskatchewan typically requires an Environmental Protection Plan (EPP). In circumstances where the project may have substantial environmental impacts, Saskatchewan Environment normally requires the completion of an Environmental Impact Assessment. Within the framework of these processes the issue of protecting and reclaiming areas of native grasslands may be addressed. Generally the reclamation recommendations focus on the stabilization of disturbed sites and the rehabilitation of such sites to as close as possible their pre-disturbance condition. There does not appear to be any provision within this process to specifically address native grassland restoration.

3.3.3.9 Guidelines for Reclamation of Sensitive Terrain in Southern Saskatchewan. The guidelines define reclamation as the process by which a disturbed area is restored to some previously defined state or pre-development condition. The general objective of reclamation of sensitive lands in southern Saskatchewan (generally native rangelands) is preservation and, where necessary, rehabilitation to a state similar to that which existed prior to the disturbance. Reclamation is determined to be necessary to safeguard other resources and land uses, such as cattle ranching; wildlife production; recreational, aesthetic, educational and scientific values; and archaeological and historical resources. The guidelines provide details regarding erosion prevention, soil protection and reclamation, and revegetation using agronomic and native species. Details regarding follow-up monitoring and assessment of the relative success of reclamation and revegetation efforts are also provided.

3.3.3.10 Guidelines for Conducting Seismic Exploration on Environmentally Sensitive Lands in Southern Saskatchewan. These guidelines empha-

size protection of environmentally sensitive grassland areas, typically rangelands, by implementing environmentally desirable procedures. The guidelines are designed to assist operators in meeting their responsibility to ensure that seismic programs on environmentally sensitive lands are undertaken with minimal short- and long-term disruption to the affected area. In doing so, the guidelines promote environmental protection and reduce the need for costly follow-up reclamation. The recommendations provided in the guidelines are aimed at avoidance of sensitive areas, protection from erosion, salvage of soil materials and revegetation. Specific reference is not made with respect to native grasslands.

3.3.3.11 An Evaluation of Reclamation Potential and Techniques for Environmentally Sensitive Areas in Southwestern Saskatchewan. An evaluation was made of the reclamation potential and reclamation techniques for environmentally sensitive area of southwestern Saskatchewan. Two parameters are recommended for defining reclamation success for surface disturbances created by oil and gas development activities on native rangelands: (1) preservation of the soil resource by topsoil salvage and adequate erosion control; and, (2) restoration of potential rangelands productivity by encouraging natural plant succession. Dryland reclamation techniques are reviewed and assessed for suitability in achieving reclamation success. A model monitoring program is described, which includes erosion control, revegetation of the disturbance and rehabilitation of disturbances that are within highly sensitive aeolian terrain (Walker et al. 1986).

3.4 MANITOBA

3.4.1 Present Status

The principle governing acts controlling land use on native prairie habitats within Manitoba include the following:

1. The Environment Act
2. The Conservation Districts Act
3. The Crown Lands Act
4. The Ecological Reserves Act
5. The Endangered Species Act
6. The Natural Resources Agreement Act
7. Provincial Park Lands Act
8. Land Rehabilitation Act
9. Fires Prevention Act
10. Noxious Weeds Act

A brief summary of these acts as they relate to prairie grassland protection follows.

3.4.1.1 The Environment Act. The intent of this Act is to develop and maintain an environmental management system in Manitoba, the function of which will be to preserve the environmental integrity of natural areas and to sustain a high quality of life. As a result of its intent, this Act provides for the environmental assessment of projects which are likely to have significant effects on the environment and provides for the recognition and utilization of existing effective review processes that adequately address environmental issues. The protection, reclamation and restoration of

native grasslands in Manitoba may be facilitated under the terms of this Act.

3.4.1.2 The Conservation Districts Act. The purposes of the Act are: to provide for the conservation, control and prudent use of resources through the establishment of conservation districts; and to protect the correlative rights of owners. Under the Act, a protected area is designated and managed primarily for its beneficial effects for resource conservation. Native grassland areas are likely targets for the establishment of conservation districts.

3.4.1.3 The Ecological Reserves Act. Under this Act, the Lieutenant Governor in Council may establish and maintain a system of ecological reserves in Manitoba. Approval is required for entering into, the use of, or production within an Ecological Reserve. Native grasslands may be governed by the Act when a native grassland area is designated as an ecological reserve.

3.4.1.4 The Endangered Species Act. The purposes of the Act are: to ensure the protection and to enhance the survival of endangered and threatened species in the province; to enable the reintroduction of extinct species into the province; and, to designate species that are endangered or threatened with extinction in the province. To ensure accomplishment of these goals, the Act specifies that no person shall undertake to kill, injure, possess, disturb or interfere with an endangered or threatened species, or to destroy, disturb or interfere with the habitat of an endangered or threatened species. Areas of native grasslands often contain a number of endangered or threatened plant and animal species and, as such, may frequently be governed under this Act.

3.4.1.5 Provincial Park Lands Act. This Act allows the province to establish, develop and maintain a system of provincial park lands for the purpose of conservation and management of the flora and fauna therein and preserving specified areas and objects of ecological or other scientific interest. No owner or occupant of land within a provincial park may alter the use of the land, from its current use, unless authorized to do so by the Minister. Permits, leases, licences, or authorizations respecting the use or occupation of provincial park lands may be granted which outline the conditions under which activities may be conducted within provincial park lands. Conditions regarding disturbances and reclamation may be specified. This has implications for the protection, reclamation or restoration of native grasslands which are located within provincial park areas.

3.4.1.6 Noxious Weeds Act. This Act establishes Weed Control Districts and laws to prevent the spread of noxious weeds. The Act has implications for the reclamation of native grasslands in that noxious weeds must be controlled during development and reclamation activities and, further, that such weeds may require control for some period subsequent to reclamation depending on land use and ownership.

3.5 CANADA

The Canadian Environmental Protection Act (CEPA) is the principle federal legislation in Canada which may influence the process of protecting and reclaiming native grasslands. However, at present there are no regulations under the act which pertain specifically to native grasslands.

The Canadian Wildlife Act and regulations pertaining to wildlife areas and national wildlife areas may have some influence on the protection and reclamation of native grasslands in Canada in that this legislation determines that specific wildlife habitats must be preserved. This is particularly important where the habitat of endangered or threatened species is involved.

Under the National Parks Act of 1979 and in cooperation with the provincial government of Saskatchewan, Grasslands National Park was established in 1989. When land acquisition is completed, the park will encompasses some 900 square kilometres of south central Saskatchewan, including native grassland plains, buttes, deep ravines and river valleys. Portions of the park include agriculturally disturbed lands which will be restored to native grasslands. Restoration efforts will be based on a detailed biophysical inventory of the park and will employ a combination of native grassland seeding programs using commercial seedstock as well as the harvesting of grass seeds within the Park boundary for subsequent use in revegetation programs (Masyk, Canadian Parks Service District Superintendent, pers. comm. 1992). There are no direct legislative requirements to restore or reclaim disturbed areas within the park.

3.6 UNITED STATES

Primary legislation, policies and programs affecting native grassland use and/or protection in the United States are summarized in the following sections.

3.6.1 Federal Jurisdiction

3.6.1.1 The National Environmental Policy Act (NEPA). NEPA requires that all federal agencies and federally funded projects address environmental issues with a uniform set of requirements designed to enhance and protect environmental quality. An Environmental Impact Statement (EIS) is required for all major actions proposed by the federal government which potentially have significant impacts on the environment. This results in fully disclosing the environmental effects of an action for public and judicial consideration of environmental issues (Robinson and Bolen 1989).

The terms and conditions of NEPA may be applied to the protection, reclamation and restoration of native grassland areas. In recent years, the terms of this Act have been increasingly applied to ecosystem quality and diversity rather than just key species protection, as was more often the case in the past.

3.6.1.2 The Endangered Species Act (ESA). The ESA requires the identification and protection of plant and animal species endangered with extinction and the regulation and trade of such species. The Act is administered by the U.S. Fish and Wildlife Service.

The ESA directs all federal agencies to ensure that their actions do not jeopardize the continued existence of any listed species or result in the adverse modification of critical habitat. In addition, the ESA requires federal agencies to carry out programs for the conservation of listed species or their habitat. This responsibility falls primarily on the following federal land management agencies: the U.S. Fish and Wildlife Service, the U.S. Forest Service, the Bureau of Land Management, the National Park Service, and the National Marine Fisheries Service.

Protection, enhancement and restoration of native grasslands can result from both the listing of an endangered native grassland species or an endangered animal species dependent on native grassland species for critical habitat. In general, native grassland protection under the ESA is more often the result of a listed animal species, as the knowledge regarding the abundance and distribution of grassland species is still limited.

3.6.1.3 The Conservation Reserve Program (CRP) of the 1985 Farm Act. Under the CRP, the federal government pays the farmer an annual rental to retire from agricultural production those lands classified by the Soil Conservation Service as highly erodible. The lands must be taken out of production for 10 years. As of January 1989, the CRP program had resulted in the enrolment of twenty eight million acres (eleven million ha) of previously farmed land. In addition, the federal government pays half the cost of establishing permanent vegetation such as grasses, trees or wildlife plantings on the enrolled lands. As a result of this program, 1988 figures showed 26% of CRP acreage had been converted to native grasses, 58% converted to non-native grasses, 6% converted to trees, 4% converted to wildlife plantings and the rest with other acceptable cover (U.S. Department of Agriculture 1988). With the recent emphasis on reestablishing native grasslands within the scientific community, the ratio of native species to non-native species can be expected to increase on CRP lands in the future (U.S. Department of Agriculture 1988).

3.6.1.4 The Surface Mining Control and Reclamation Act. It is the purpose of this Act to establish a nationwide program to protect society and the environment from the adverse effects of surface coal mining operations. The Act recognizes that many surface mining operations result in the disturbance of surface areas in a manner which diminishes their use for commercial, industrial, residential, recreational, agricultural and forestry purposes. Because of the diversity in terrain, climate, biologic, chemical and other physical conditions in areas subject to mining operations, the primary governmental responsibility for developing, authorizing, issuing, and enforcing regulations for surface mining and reclamation operations, subject to this Act, generally rests with the individual States. Federal programs are applied where States have failed to submit a suitable State program covering surface coal mining and reclamation operations, or where mining is undertaken on Federal lands.

Pursuant to the Act, permit applications for surface coal mining must include comment on the existing environmental condition, potential impacts and appropriate mitigation measures relative to the proposed operation. Each reclamation plan, submitted as part of the permit application, pursuant to any approved State or Federal program under the provision of the Act, must demonstrate that the level of reclamation required by the State or Federal program can be accomplished. The main provisions within the Act are related to agricultural production and the preservation or reclamation of lands for human use. The Act does not specifically relate to native grassland areas. However, many reclamation requirements may be applied to the protection or reclamation of native grasslands. The minimum environment-oriented requirements are summarized as follows:

1. Mining operations should be conducted such that the minimum possible land area is affected. Protection of adjacent lands from erosion, slope instability, contamination or other impacts is required during the course of mining operations.
2. The principle goal of reclamation is to restore the disturbed land to a condition equal to or better than its pre-disturbance condition. Further, the reclaimed land must be suitable for the permit applicants declared end land use, and consistent with applicable land use policies and plans.
3. During reclamation all backfill materials should be compacted and graded to the approximate original contour. Of specific importance is the creation of a landscape which is not prone to slope instability or erosion.
4. All surface areas, including spoil piles, affected by the surface coal mining and reclamation operation must be stabilized and protected to effectively control erosion and attendant air and water pollution.
5. Topsoil or the best available subsoil should be removed, prior to land disturbance, and either reclaimed to backfilled areas or stockpiled. Topsoil (or subsoil) stockpiles should be developed in a manner such that they will not be negatively affected by adjacent spoil piles or by mining activities and such that they will be protected from erosion. During reclamation, stockpiled topsoil or subsoil should be restored to graded areas. For prime farmlands, specifications for soil removal, storage, replacement and reconstruction shall be established by the Secretary of Agriculture, and the operator shall, as

a minimum, be required to segregate the topsoil (A horizons) and subsoil (B horizons) materials such that they may be protected, replaced and regraded to develop a root zone material, with proper compaction and uniform depth over the regraded spoil material, suitable for cultivation. Upon reclamation the topsoil must be capable of sustaining vegetation growth.

6. Disturbances to the prevailing local and regional hydrologic balance should be avoided during surface mining operations. The quality and quantity of water in surface and groundwater systems should be protected. If approved in the mining and reclamation plan, permanent impoundments of water may be developed as part of reclamation activities. There is some ability to develop or enhance wildlife habitat in association with water bodies.

7. Waste materials should be buried, contained by an impermeable barrier and contoured to match the surrounding landscape. Off-site disposal of spoil or other waste materials is not allowed unless a specific permit is issued.

8. All reclamation efforts should proceed in an environmentally sound manner and as contemporaneously as practicable with the surface mining operations.

9. Construction, maintenance and post-mining conditions of access roads should be conducive to the prevention of erosion, siltation and pollution. Roads and other access ways should not be developed within drainage channels where they will be affected by the normal flow of the water.

10. As the final stage of reclamation for mined areas, and all other lands affected, a diverse, effective and permanent vegetative cover must be established. This vegetation cover must be of the same seasonal variety native to the area and capable of self-regeneration and plant succession, at least equal in extent to the natural vegetation cover of the area. Introduced species may be used in the revegetation process when they are desirable and necessary to achieve the approved post-mining land use.

11. As part of the permit application and reclamation plan the operator assumes responsibility for successful revegetation for a period of 5 years after the last year of augmented seeding, fertilizing, irrigation, or other work

necessary to ensure the development of a suitable vegetation cover. In areas where annual precipitation is 650 mm (26 inches), or less, the period of operator responsibility and liability is 10 years.

Under the terms of the Act operators are required to use the best technology currently available to minimize disturbances and adverse impacts of surface mining operations on fish, wildlife, and related environmental values, and achieve enhancement of such resources where practicable. The reclamation conditions outlined in this Act, particularly those summarized by points 10 and 11 above, have significant implications for the protection and reclamation of native grassland areas following surface mining operations. Other legislation associated with surface disturbances in the United States are typically related to the terms and provisions of the Surface Mining Control and Reclamation Act.

3.6.2 State Jurisdiction

In general, most states have instituted their own version of NEPA for all state actions or state funded actions which may have environmental impacts. In those instances where state and federal cost sharing occurs, states generally defer to NEPA for environmental guidelines.

In addition, most states also have their own endangered species programs which are designed to conserve plant and animal species that, regardless of their national status under the ESA, are endangered within the state. These programs often fall within non-game wildlife management programs which recognize the importance of native grasslands to many non-game and endangered species and consequently, have objectives for the protection or reestablishment of native grasslands.

Many states support the federal CRP program by further subsidizing the establishment of native vegetation on enrolled agricultural lands. They also contribute considerable manpower, in a consultative role with farmers, to help maximize CRP benefits to wildlife and native habitat.

4. BIOPHYSICAL SETTINGS

4.1 BACKGROUND

Three major climatic regimes, or ecoprovinces are identified by Strong and Leggat (1992) within Alberta. These are the prairie, cordilleran and boreal ecoprovinces. The native grasslands of interest in this report are located principally within the prairie ecoprovince, specifically within the dry mixed grass (formerly the short grass), mixed grass, fescue grass, and the aspen parkland ecoregions. Some additional native grassland areas occur within the montane ecoregion of the cordilleran ecoprovince. The ecoregions identified for discussion are illustrated in Figure 2.

Strong and Leggat (1981) and Strong and Leggat (1992) have identified the climatic, terrain, soils and vegetation attributes typically associated with each ecoregion identified above. These descriptions are summarized here to provide a basis for subsequent review of the degree and extent of native grassland disturbance within the province. In addition, each ecoregion description demonstrates the integrated nature of climate, terrain, soils and vegetation which provides the biophysical setting for a discussion of native grassland reclamation and restoration. It should, however, be recognized that the data provided are general in nature and may not apply to all site-specific conditions within each ecoregion.

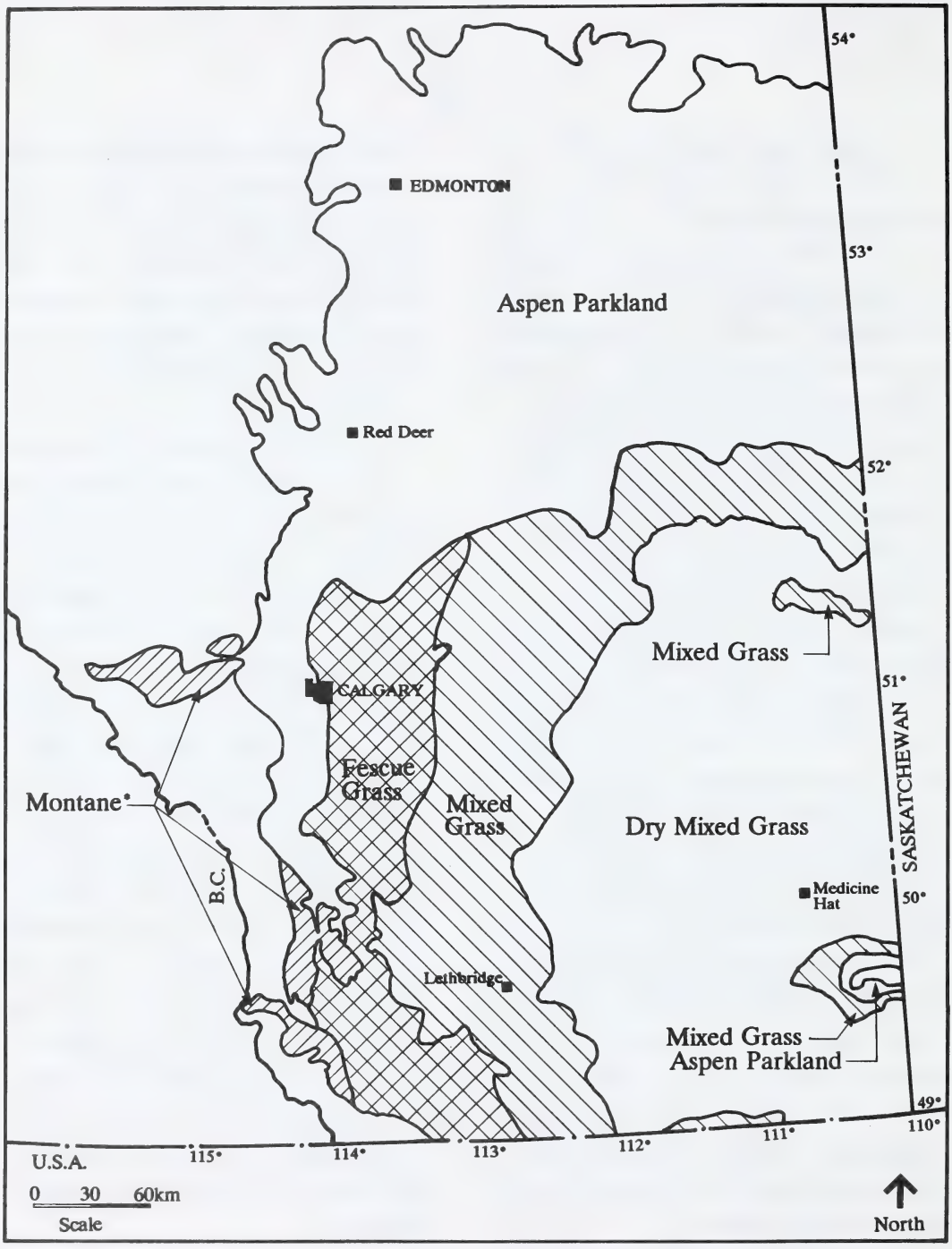
The prairie ecoprovince is located within a continental climatic regime, characterized by cold winters, short, warm summers, and low annual precipitation. The primary controlling climatic factors are latitude and air stream influences. Generally conditions become cooler and moister from ecoregions in the southeast to the northwest. Large diurnal temperature fluctuations are noticeable during the summer months. There is an overall aridity within the prairie ecoprovince, although this condition is most prevalent in the southeast, where evapotranspiration is high.

4.2 DRY MIXED GRASS ECOREGION

The dry mixed grass ecoregion, formerly referred to as the short grass ecoregion (Strong and Leggat 1981), is located in the southeast corner of Alberta (Figure 2). Covering an area of roughly 7.2% of the province this ecoregion represents the largest grassland ecoregion in Alberta. Its extent is mapped largely along the boundary of the Brown Chernozemic soil zone in Alberta and approximately half of the ecoregion has been significantly altered by agricultural activities. The location and extent of remaining native grassland areas within this ecoregion have not been well defined. Despite extensive habitat alteration, this ecoregion supports an abundant and diverse wildlife community. Diversity is highest along drainage systems where tree and shrub vegetation is present. Locations of particularly high wildlife diversity and productivity are the Milk River valley, the Suffield Military Reserve, the Middle Sand Hills and the Pakowki Lake - Etzikom Coulee area.

4.2.1 Climate

The climate of the ecoregion is semi-arid to arid continental, and represent the driest of Alberta's grassland ecoregions. The mean annual



*Montane Ecoregion is in the Cordilleran Ecoprovince

Figure 2. Ecoregions of the Prairie Ecoprovince in Alberta.
Source: Strong and Leggat, 1981; Strong, 1991.

temperature for the ecoregion is 5°C, with summer temperatures ranging from 23°C to 28°C and winter temperatures averaging -7.2°C. There is an average of 115 frost free days annually and the ecoregion experiences a range of 1479 to 1646 growing degree days (above 5°C). Temperature and length of the growing season are not generally limiting for plant growth; however, the moisture deficiency is a severely limiting factor. This is also a principle factor which may govern the nature and success of reclamation and restoration efforts within the ecoregion. The agroclimatic moisture balance averages -401 mm but may be as high as -506 mm during drier periods.

Precipitation within this ecoregion is low and variable. Total precipitation averages 272 mm annually. Summer precipitation levels range from 88 to 233 mm and may represent up to 90% of the total annual precipitation. June is typically the highest rainfall month and late summer droughty conditions are typical. Accordingly, revegetation programs should be undertaken in the early spring (late April) to maximize the water availability for germination and to allow for plants to become established prior to the later summer droughty periods.

Winter precipitation averages 42 cm in this ecoregion, resulting in shallow snow depths and relatively few days with continuous snow cover. The cold winter temperatures and shallow snow cover result in harsh winter conditions for perennial vegetation, alleviated only periodically by warm chinook winds.

4.2.2 Terrain

The dry mixed grass ecoregion is located within the Alberta Plains physiographic region of Alberta (Bostock 1970; Pettapiece 1986). Figure 3 and Table 1 outline the specific physiographic subdivisions and associated landform characteristics. Within each physiographic subdivision the terrain may be highly variable. The ecoregion is dominated by draped and ice stagnation morainal deposits consisting of an unsorted mixture of clay, silt, sand and gravel, with local water-sorted material and bedrock (Shetsen 1987). The terrain varies from flat and undulating to rolling, hummocky and ridged reflecting variations in till thickness and underlying bedrock topography. Depth of the till deposits may range from less than 25 m on uplands to over 100 m in buried valleys.

Zones of glaciofluvial deposits occur paralleling existing drainage channels. Occurring up to 40 m thick, these deposits are characterized by a flat to gently undulating topography. Textures range from coarse sands and gravels to fine clay (Shetsen 1987). Between the channels of the Red Deer and South Saskatchewan Rivers, north of Medicine Hat, several areas of aeolian and ice-contact lacustrine and fluvial deposits occur. The aeolian deposits are fine and medium-grained sand and silt materials up to 7 m thick. The landscape is characterized by undulating to rolling topography and by longitudinal and parabolic dunes and blowouts (Shetsen 1987). Glaciofluvial deposits as well as stream and slope eroded deposits occur along existing drainage channels.

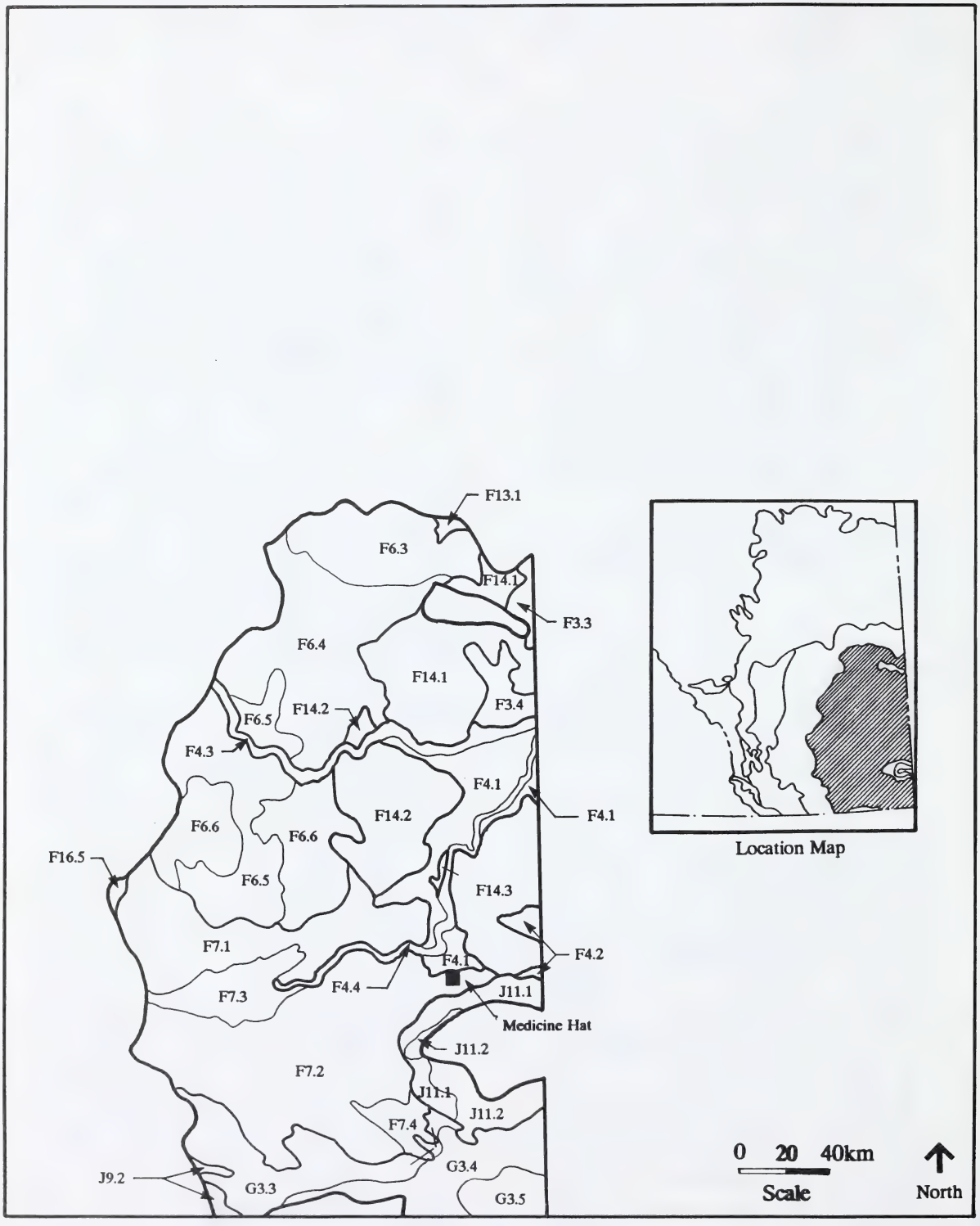


Figure 3. Physiographic Subdivisions of the Dry Mixed Grass Ecoregion.

Table 1. Physiographic Subdivisions of the Dry Mixed Grass Ecoregion.

Section	District	Landform
F. Eastern Alberta Plains		
F3 Snipe Lake Plain	F3.3 Sibbald Plain	GLu
	F3.4 Acadian Plain	GLu
F4 Bigstick Lake Plain	F4.1 Cavendish Plain	GFu
	F4.2 Walsh Plain	GLul
	R4.3 Red Deer Valley	Us-D
	F4.4 South Saskatchewan Valley	Us-D
F6 Sullivan Lake Plain	F6.3 Sounding Creek Plain	GFbv/Mu.Mu
	F6.4 Berry Creek Plain	Mbv/Ru.Mu
	F6.5 Matzhiwin Plain	GFu.Eu(GL)
	F6.6 Kininvie Plain	Mbv/Ru
F7 Coulee Plain	F7.1 Enchant Plain	Mu.GLvb/Mu
	F7.2 Etzikom Plain	Muh.GLvb/Mu
	F7.3 Fincastle Plain	GFu.GFvb/Mu
	F7.4 Pakowki Plain	GLi.Er.Mu
F13 Neutral Hills Uplands	F13.1 Neutral Upland	Mh.Mb/Rm(GF)
F14 Rainy Hills Uplands	F14.1 Oyen Upland	Mhu
	F14.2 Rainy Hills Upland	Mhu
	F14.3 Schuler Upland	Mhu
F16 Cooking Lake Uplands	F16.5 Lomond Upland	Mhu
G. Western Alberta Plains		
G3 Southwest Plains	G3.3 Verdigris Plain	Mu.Mvb/Rm
	G3.4 Lost River Plain	Mvb.Rm-D
	G3.5 Sage Creek Plain	GL.DFu(M)
J. Southern Alberta Uplands		
J9 Milk River Upland	J9.2 Milk River Plain	Mu.Fut(GL)
J11 Cypress Hills Upland	J11.1 McAlpine Benchland	Mu.Mbv/Ri-D
	J11.2 Elkwater Benchland	Mh.Mbv.Rm-D

LEGEND		
Composition (Material)	Surface Expression	
E - eolian	u - undulating	v - veneer
F - fluvial	m - rolling	D - dissected
GF - glaciofluvial	h - hummocky	l - level
GL - glaciolacustrine	r - ridged	i - inclined
M - morainal (till)	s - steeply inclined	t - terraced
R - rock	b - blanket	
U - undifferentiated		

In general, the nature of surface materials and terrain is highly variable.

4.2.3 Soils

The boundary of the dry mixed grass ecoregion commonly follows the boundary of the brown soil zone in Alberta. Soils of the Brown Chernozem and Solodized Solonetz great groups dominate this area (Pettapiece 1989). These are soils that occur under sub- to semi-arid conditions and have brownish-coloured topsoil (A) horizons. They are associated with xerophytic and mesophytic grass and forb vegetation where the topsoil is frequently characterized by a low organic matter content. The combination of a relatively arid climate, low soil organic matter and sparse vegetation cover makes these soils difficult to reclaim if severe surface disturbance occurs.

Glacial till deposits, with textures varying from sandy loam to clay, are the most common soil parent materials within this ecoregion. A higher degree of profile variability occurs along drainage channels and coulee complexes where parent materials and terrain conditions may change over short distances from one area to the next. Agroecological resource areas A1, C1 - C7, D1 - D3 and E1 - E4 have been mapped within this ecoregion (Pettapiece 1989). The landforms, soil texture and soil type associated with these areas are outlined in Table 2.

Profiles within this ecoregion are moderately well to well drained and prone to droughty conditions during dry, summer periods. The area is designated as having an agroclimate of 3A, with moderate moisture limitations and a frost free period of over 100 days (Pettapiece 1989). Soil capability for agriculture is rated as Class 3, based on the climatic limitation. Poorer capability classes may result from other locally limiting factors such as adverse topography or solonetzic soil conditions. Small areas of Class 1 and 2 lands occur locally, associated with moister conditions along the South Saskatchewan and Oldman rivers.

4.2.4 Vegetation

The following description of the dry mixed grass prairie is taken primarily from Clarke et al. (1942).

To adapt to the dry conditions of this ecoregion, the dominant plants are usually low-growing perennial grasses with well-developed, finely branched root systems. Forbs and dwarf shrubs are also low growing and have reduced leaves, a hairy growth habit and other features to reduce water loss. The annual growth cycle of the plants is well adapted to seasonal conditions, with the majority of species (blue grama grass being an exception) beginning growth in April, growing rapidly during April, May and June, then slowing during the hot, dry months. Most plants produce seed abundantly only in growing seasons when precipitation is above normal. Vegetative reproduction, for example by rhizomes, is common.

A spear grass (mainly needle-and-thread)-blue grama grass association is considered modal for this ecoregion. Other common graminoids include western and northern wheat grass, june grass, Sandberg's bluegrass, plains muhly, low sedge, and thread-leaved sedge. Although wheat grasses, spear grasses and june grasses are also

Table 2. Agroecological Resource Areas of the Grassland Ecoregions.

Ecoregion	Area	Landform	Texture	Soils	Agroclimate
DMG	A1	H-U	L-SL	BR-SS	3A
MG	B1	S(L)	L	DB-BL	2AH
DMG	C1	U(H)	S-L	BR	3A
DMG	C2	U	C	BR	3A
DMG	C3	U	SiC-SiL	BR	3A
DMG	C4	H(U)	L - CL	BR(DB)	3A(2A)
DMG	C5	H(U)	L(SL)	BR	3A
DMG	C6	H-U	L - CL	BR	3A
DMG	C7	U-H	L - CL	DB	2A
DMG	D1	U(H)	L - SiL	BR	3A
DMG	D2	U	SL(S)	BR	3A
DMG	D3	U	L(SL)	BR	3A
DMG	E1	U	SiL-SL(S)	BR(SS)	3A
DMG	E2	U	L - CL	SS-BR	3A
DMG	E3	U	L - CL	SS(BR)	3A
DMG/MG	E4	U	SL-L	SS(BR,DB)	3A(2A)
MG	F1	U(L)	SiL(SiC)	DB	2A
MG	F2	U	SiL(SL)	DB	2A
MG	F3	U(M)	SiL	DB	2A
MG	F4	U	SL(L)	DB	2A
MG	F5	H	L - CL	DB	2A
MG/FG	G1	U(M)	SiL-SiC	DB	2AH
MG/FG	G2	U-M	C	DB	2AH
MG	G3	H(U)	L - CL	DB	2AH
MG	G4	H(U)	L - CL(SL)	DB	2AH
AP	H1	U(L)	L - CL	SS(DB)	2AH
AP	I1	U(M)	SiL(SL)	DB	2AH
AP	I2	H(U)	S(SL)	DB	2AH

continued . . .

Table 2. Continued.

Ecoregion	Area	Landform	Texture	Soils	Agroclimate
MG/AP	I3	H(S,U)	L - CL	DB	2AH
FG	J1	U(H)	SiC-CL	BL	2AH-3H
MG/FG	J2	H-U	SiL-CL	DB-BL	2AH
FG/M	J3	H-S	L - CL	BL	4H-5H
M	J4	H-S	L - CL	BL	4H-5H
FG	K1	U	SiL-CL	BL	2AH
AP	L1	U	L - CL	SS-BL	2H
AP	L2	U	L - CL	BL	2H
AP	L3	H(U)	L - CL(SL)	BL	2H
AP	M1	U(H)	L - CL	BL	2H
AP	M2	H(U,M)	L - CL	BL	2H
AP	N1	U(H)	SiL(C,S)	BL(SS)	2H(3H)
AP	N2	U(L)	SiC-SiL	BL(DG)	2H
AP	N3	U	L - CL	BL(SS)	2H
AP	N5	H	L - CL	GL-DG	3H
FG/AP	O1	U(M)	L - CL	BL	3H
AP	O2	U	L - CL(C,S)	DG(BL)	3H
AP	O3	U(H)	L - CL	BL	3H
AP	O4	H(M,U)	L - CL	BL(DG)	3H
AP	O5	H-U	L - CL	GL-DG	3H
FG/AP	O6	M(U)	L - CL	BL-DG	4H(3H)
AP	P3	H	CL(C)	GL(DG)	3H
AP	S1	U	SiL(SL)	GL(O)	4H
AP	S2	U-H	CL(C)	GL(O)	4H-3H
AP	S3	U(L)	SiC(SL)	GL(O)	4H
AP	S4	U(H)	CL-SiC	GL(O)	4H
AP	S5	H(U)	CL	GL(O)	4H

continued . . .

Table 2. Concluded.

Legend		
ECOREGION:	DMG -	Dry Mixed Grass
	MG -	Mixed Grass
	FG -	Fescue Grass
	AP -	Aspen Parkland
	M -	Montane
LANDFORM:	U or L -	undulating and level plains with slopes of <5%
	H -	hummocky uplands or hillands with slopes of 5-15%
	M -	rolling uplands with slopes of 5-15%
	S -	steeplands with slopes of >15%
TEXTURE:	S -	coarse and loamy sands
	SL -	moderately coarse sandy loams
	L -	medium to moderately fine loams
	SiL -	silt loams
	CL -	clay loams
	SiC -	fine silty clays
	C -	clays
SOIL DEVELOPMENT:	Chernozemic:	BR - Brown
		DB - Dark Brown
		BL - Black
		DG - Dark Gray
	Solonetzic:	SS - Solodized Solonetz
		SO - Solods and Solonetzic Intergrades
		GL - Luvisolic-Gray
		DG - Dark Gray
	Brunisolic:	BS
	Organic:	O
AGRO-CLIMATE:	3A - moderate moisture limitation	
	2A - slight moisture limitation	
	2H - slight heat limitation	
	3H - moderate heat limitation	
	4H - severe heat limitation	
	5H - very severe heat limitation	

found in mixed prairie, they tend to be shorter in the dry mixed prairie due to less moisture availability. Prairie selaginella, moss phlox, fringed sage, hairy golden aster, broomweed, low whitlow-wort, scarlet mallow and small-leaved everlasting are characteristic forbs.

Species composition of the dry mixed grass prairie varies considerably as a result of differences in such factors as soil conditions, topography and grazing pressure.

Where conditions are particularly dry, such as on south-facing slopes, and shallow or eroded soil, blue grama grass often predominates and prickly pear cactus, yellow umbrella-plant, moss phlox, low whitlow-wort, Colorado rubber-plant and spiny ironplant frequently occur. Sagebrush is of scattered occurrence, being most abundant on sandy soils. Blowout areas on Solonetzic soils are sparsely vegetated with such species as broomweed, prickly pear, Nuttall's atriplex, and winter fat. Rhizomatous species, such as western wheat grass and low sedge are common.

As moisture increases, needle-and-thread becomes more abundant, although on moist alluvial flats, particularly with clay and silt type soils, western wheat grass dominates, largely replacing both needle-and-thread and blue grama grass. Moderately high moisture sites, such as depressions, often contain large amounts of slender wheat grass, green needle grass and Canby bluegrass. In ravines, coulee bottoms and on north-facing slopes, moisture conditions are often favourable enough to permit shrub growth of willows, saskatoon, wild rose, wolf-willow and buckbrush.

Non-saline wet meadows are populated with such species as creeping spike-rush, tufted hair grass, sedges and Baltic rush, while Nuttall's salt-meadow grass, salt grass, foxtail barley and members of the goosefoot family typically occupy more saline sites.

Along drainage channels and on floodplains, cottonwoods, willows and water birch provide a unique band of riverine habitat in the ecoregion.

Species composition of the dry mixed grass prairie is dynamic, reflecting changes in such factors as climate and grazing pressure. In general, drier climatic conditions and/or increasing grazing pressure results in a decrease in the cover of mid-grasses such as needle-and-thread, compared to short grasses such as blue grama grass, Sandberg bluegrass; and fringed sage. Impacts of grazing on native grassland ecoregions is treated in more detail in Section 5.2.1.

4.3 MIXED GRASS ECOREGION

The mixed grass ecoregion, identified by Strong and Leggat (1981), and revised by Strong and Leggat (1992), forms a band along the north and west edge of the dry mixed grass ecoregion (Figure 2). Isolated areas of this ecoregion also occur within the dry mixed grass ecoregion, generally corresponding to elevated landforms (the Cypress Hills, the Sweetgrass Hills and an area near Oyen). Encompassing an area of roughly 4.8% of the province, this ecoregion is approximately two thirds the size of the dry mixed grass ecoregion. The boundaries of this ecoregion correspond approximately to the dark brown soil

zone in Alberta. To the east is the dry mixed grass ecoregion, characterized by brown soils, and to the west and north are the fescue grass and aspen parkland ecoregions, characterized by black soils. Soil boundaries provide the main indicator of ecoregion boundaries as the native vegetation in this area is largely disturbed by agriculture.

Wildlife species and habitat occurring in the mixed grass ecoregion are similar to those previously described for the dry mixed grass ecoregion. The majority of contiguous tracts of native vegetation and associated wildlife diversity is found along drainage channels and in coulees. A transitional zone is evident along the border of the aspen parkland ecoregion, where the nature of species and habitat becomes more diverse. Examples of important wildlife areas include the Red Deer and Bow River valleys and the Little Fish Lake - Hand Hills area.

4.3.1 Climate

The climate is semi-arid continental, with slightly warmer winters, cooler summers and moister conditions than experienced by the dry mixed grass ecoregion. Chinook winds are fairly frequent in the southern portion of the ecoregion, providing considerable relief from the cold winter temperatures. The mean annual temperature for this ecoregion is 5.3°C, with a mean of 15.2°C during the summer and a winter mean of -5.2°C. There is generally in excess of 100 frost free days annually, similar to the conditions of the dry mixed grass ecoregion. Summertime precipitation is concentrated in June and it is the semi-arid late summer conditions which promote the development of characteristic grassland vegetation. The agroclimatic moisture balance for the ecoregion may range between -225 mm and -464 mm, with a mean value of -360 mm. The growing season is characterized by an average 1442 degree days (>5°C).

Total precipitation for the ecoregion averages 326 mm annually, with summertime rainfall of 176 mm accounting for about 54% of the total. There is a general increase in precipitation from east to west. Winter snowfall averages 52 cm and tends to form a deeper, longer lasting snow cover accumulation than occurs within the dry mixed grass ecoregion. Hence the vegetation of this ecoregion is subject to less harsh winter conditions and may have an abundance of springtime moisture.

4.3.2 Terrain

The mixed grass ecoregion is located within the Alberta Plains physiographic region of Alberta (Bostock 1970; Pettapiece 1986). Figure 4 and Table 3 outline the specific physiographic subdivisions and landform characteristics. There is an increase in elevation from east to west within the ecoregion and terrain is variable both within and between physiographic subdivisions.

The ecoregion is characterized by a highly variable pattern of surficial deposits, including undulating to hummocky morainal tills, very gently undulating to level glaciolacustrine deposits, glaciofluvial and stream and slopewash eroded deposits, and aeolian deposits (Shetsen 1987).

Draped and ice stagnation morainal deposits, along with glacial till of uneven thickness

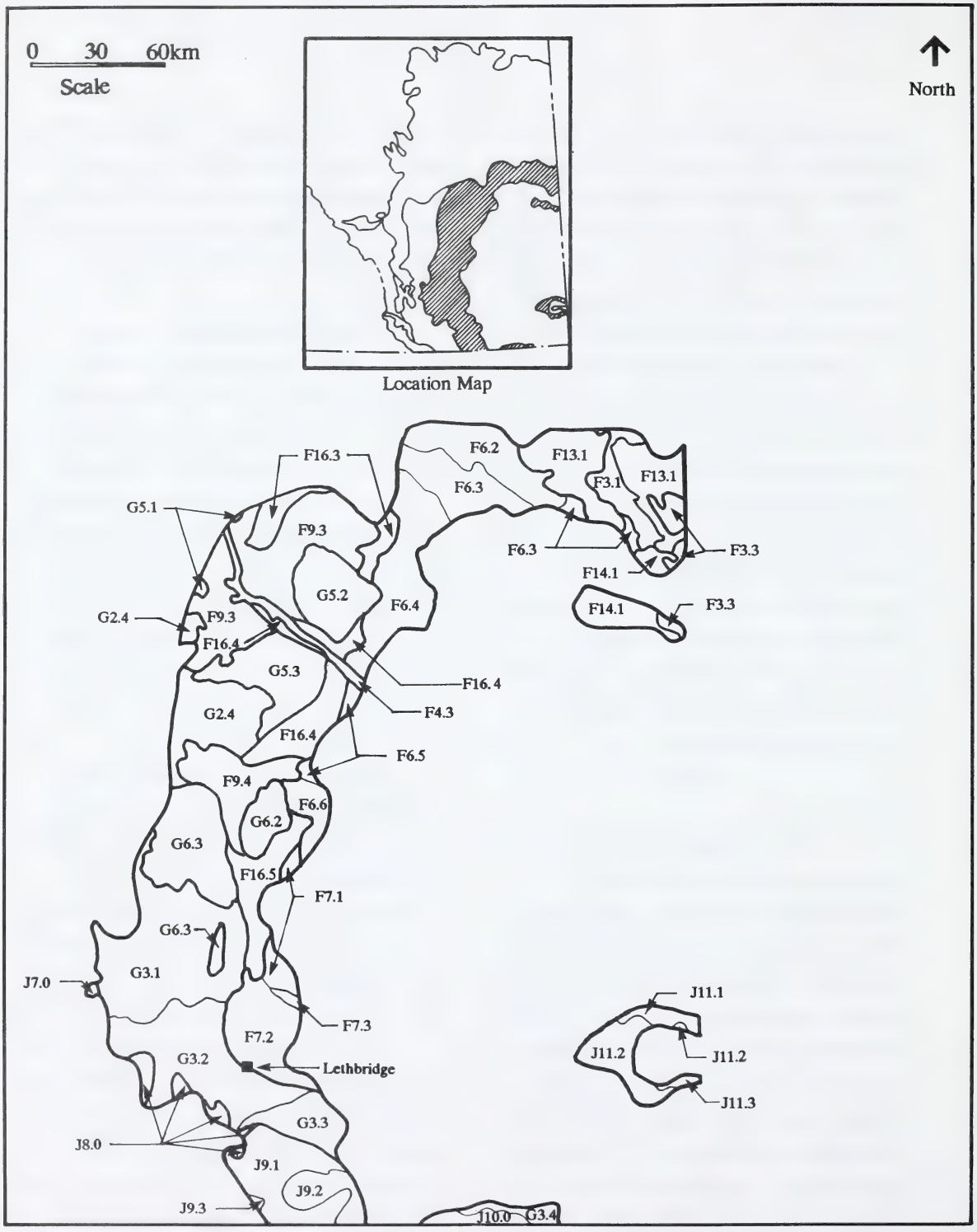


Figure 4. Physiographic Subdivisions of the Mixed Grass Ecoregion.

Table 3. Physiographic Subdivisons of the Mixed Grass Ecoregion.

Section	District	Landform
F. Eastern Alberta Plains		
F3 Snipe Lake Plain	F3.1 Ribstone Plain	GFu.Er
	F3.3 Sibbald Plain	GLu
F4 Bigstick Lake Plain	F4.3 Red Deer Valley	Us-D
F6 Sullivan Lake Plain	F6.2 Castor Plain	Mbv/Ru.Mu
	F6.3 Sounding Creek Plain	GFbv/Mu.Mu
	F6.4 Berry Creek Plain	Mbv/Ru.Mu
	F6.5 Matzhiwin Plain	GFu.Eu(GL)
	F6.6 Kininvie Plain	Mbv/Ru
F7 Coulee Plain	F7.1 Enchant Plain	Mu.GLvb/Mu
	F7.2 Etzikom Plain	Muh.GLvb/Mu
	F7.3 Fincastle Plain	GFu.GFvb/Mu
F9 Big Rivers Plains	F9.3 Drumheller Plain	GLum.GLvb/Mm
	F9.4 Blackfoot Plain	GFur.Eh
F13 Neutral Hills Uplands	F13.1 Neutral Upland	Mh.Mb/Rm(GF)
F14 Rainy Hills Uplands	F14.1 Oyen Upland	Mhu
F16 Cooking Lake Uplands	F16.3 Rumsey Upland	Mhu
	F16.4 Crawling Valley Upland	Mhu
	F16.5 Lomond Upland	Mhu
G. Western Alberta Plains		
G2 Olds Plain	G24 Strathmore Plain	GFu.GFvb/Ru-D
G3 Southwest Plains	G3.1 Little Bow Plain	GLvb/Mu.Mu(GF)
	G3.2 Three Rivers Plain	GFu.AGLu.Mu
	G3.3 Verdigris Plain	Mu.Mvb.Rm
	G3.4 Lost River Plain	Mvb/Rm-D
G5 Drumheller Uplands	G5.1 Delburne Upland	Mh.Mb/Rm
	AG5.2 Hand Hills	Mb/Rm.Muh(GF)
	G5.3 Wintering Hills	Mh.Mb/Rm(GF)
G6 Blackfoot Uplands	G6.2 Majorville Upland	Mhu
	G6.3 Vulcan Upland	Mb/Rm.Muh(GL)
J. Southern Alberta Uplands		
J7 Porcupine Hills Upland	J7.0 Porcupine Hills	Mbv/Rvm-D
J8 Cardston Plain	J8.0 Cardston Plain	GLu.Muh
J9 Milk River Upland	J9.1 Milk River Ridge	Mhu.Mbv/Rm-D
	J9.2 Milk River Plain	Mu.Fut(GL)
	J9.3 Del Bonita Plateau	Ev/Fl

Table 3. Concluded

Section	District	Landform
J10 Sweetgrass Upland	J10.0 Sweetgrass Upland	Mhu/Mbv.Ri-D
J11 Cypress Hills Upland	J11.1 McAlpine Benchland	Mu.Mbv/Ri-D
	J11.2 Elkwater Benchland	Mh/Mbv/Rm-D
	J11.3 Cypress Hills Plateau	Ev/Fl

LEGEND	
Composition (Material)	Surface Expression
E - eolian F - fluvial GF - glaciofluvial GL - glaciolacustrine M - morainal (till) R - rock U - undifferentiated	u - undulating m - rolling h - hummocky r - ridged s - steeply inclined b - blanket v - veneer D - dissected l - level i - inclined t - terraced

(up to 30 m) dominate. The topography is flat to strongly hummocky, with occasional morainal ridges. In some areas the surface is modified by upland and stream erosion or deposition. Till deposits are variable, consisting of gravels, cobbles, stones and boulders in a clay loam to sandy loam matrix.

Areas of glaciolacustrine materials are characterized by considerably lower variations in relief in comparison to adjacent morainal deposits. The materials are variable, ranging from coarse sands and gravels to fine clays. Ice-rafted stones are frequently present.

Drainageways associated with the Oldman, Bow and Red Deer rivers and their tributaries contain variable glaciofluvial, stream and slope-wash eroded deposits. Generally deposits of up to 25 m may be expected and bedrock exposures occur in some areas along the drainage channels.

Aeolian landscapes are characterized by a series of longitudinal and parabolic dunes and associated scour or deflation blowout areas. Surface textures are sandy and the area is rapidly drained. Aeolian deposits rarely exceed 7 m in depth.

4.3.3 Soils

The mixed grass ecoregion is strongly associated with the dark brown soil zone of Alberta although there is considerable overlap with the brown soil zone to the east and the black soil zone to the north and west. Soils of the Dark

Brown Chernozem group dominate the ecoregion, characterized by moderately well to well drained-profiles with dark brown, organic-enriched topsoil (A) horizons. Where native vegetation occurs, the profiles are associated with a cover of mesophytic grasses and forbs under semi-arid climatic conditions. In response to drier conditions, a zone of mixed Dark Brown and Brown Chernozem and Solodized Solonetz soils occur along the boundary between this ecoregion and the dry mixed grass ecoregion to the east (Pettapiece 1989). Similarly there is a gradational zone of dark brown and black soils, developing in response to site-specific conditions, occurring along the boundary between this ecoregion and the fescue grass and aspen parkland ecoregions to the west and north, respectively.

The relationship of agroecological resource areas and soils within this ecoregion is outlined in Table 2. A high degree of profile variability occurs along drainage channels and in coulee complexes where parent materials and terrain conditions may change over short distances from one area to the next.

Soils within this ecoregion are loamy in texture and have a moderate moisture holding capacity. The agroclimate is designated as 2A, with associated moisture limitations, and 2AH, with slight moisture and heat limitations (Pettapiece 1989). The frost free period is over 100 days. Soil capability for agriculture is Class 2 to 3, with poorer class lands strongly limited by adverse topography, solonetzic soil conditions, or other factors. Some areas of Class 1 land are associated with moister conditions along the drainage channels.

4.3.4 Vegetation

The term mixed grass acknowledges the predominance of intermediate height grasses (mid grasses) and short height grass. Modal sites within this ecoregion are dominated by spear grasses, wheat grasses, and blue grama grass. Four main vegetation types may be recognized in Alberta (Coupland 1950; 1952): spear grass-blue grama grass, blue grama grass-spear grass, spear grass-wheat grass and wheat grass-june grass.

The spear grass-blue grama grass type is the most widespread, occurring on medium-textured soils and intermediate slopes in moister parts of the brown soil zone, lower slopes of the drier brown soil zone and upper slopes in the dark brown soil zone. Typical graminoids are needle-and-thread, western porcupine grass, blue grama grass, low sedge, june grass, northern and western wheat grass and thread-leaved sedge. Fringed sage, moss phlox and prairie selaginella are the chief forbs, with lesser amounts of such species as scarlet mallow, prairie crocus, goldenrods, hairy golden aster, milk vetches and cinquefoils.

The blue grama grass-spear grass type occupies the drier portions of this ecoregion and has been discussed in the preceding section (4.2.4) of this report.

The spear grass-wheat grass type occurs in areas with higher moisture occupying much of the dark brown soil zone and lower slopes in the moist part of the brown soil zone. It is more

luxuriant in appearance than the two previously discussed types because the mid grasses are more conspicuous. Needle-and-thread, western porcupine grass, northern and western wheat grass are the dominant species, with needle-and-thread replacing western porcupine grass and western wheat grass replacing northern wheat grass in the drier regions to the east and south. June grass, blue grama grass and low-growing upland sedges are less abundant. Forb composition is similar to the spear grass-blue grama grass type, however fringed sage is more common.

The wheat grass-june grass vegetation type is situated on clay soils of former lakebeds, characterized by abundant mid grasses such as northern and western wheat grass, june grass, and green needle grass; low sedge and occasional winter fat. There are fewer forbs here than in preceding types, however fringed sage, moss phlox, yarrow, small-leaved everlasting, tufted white prairie aster and wild blue flax are typically present. Achuff et al. (1988) note that western wheat grass, june grass, Pursh's plantain and gumweed are common on heavy clays.

The following description of specific habitats is derived primarily from Achuff et al. (1988). Solonetzic soils occupy a large area in the central part of the mixed grass ecoregion. In the south, these are dominated by blue grama grass and western wheat grass on fine textured soils, and on coarse soils, by these species plus june grass and needle-and-thread. Solonetzic areas further north have not ben well-documented, however spear grasses appear to be more prevalent there.

Sand dunes support a range of vegetation from pioneering species on active dunes to tree and shrub communities in more stabilized conditions. The most widespread vegetation type is composed of needle-and-thread, sand grass, june grass and low shrubs including sagebrush, wolf-willow, buckbrush, and prickly wild rose. Taller shrubs such as choke cherry, water birch, Bebb's willow and thorny buffaloberry; and trees such as trembling aspen and western cottonwood occur in stabilized depressions and protected sites. Predominant forbs are plains wormwood, hairy golden aster, scurf pea, and low goldenrod. The vegetation of active dune sites is composed primarily of sand dropseed, Indian rice grass, wild begonia, scurf pea, annual sunflower, skeleton-weed, plains wormwood and sand grass.

Wetlands within the mixed grassland are of three major types: wet meadows characterized by grasses, low shrubs and several forbs; shallow marshes composed of sedges, rushes and spike-rushes; and open alkali wetlands on solonetzic soils vegetated primarily with bulrushes.

Shrubs such as wolf-willow, buckbrush, saskatoon, wild gooseberry and choke cherry are common in cooler, moister areas such as on north-facing slopes and ravines, while sagebrush is frequent on drier terraces. River valleys are characterized by willows, water birch, wild roses, balsam poplar and cottonwoods.

The reader is directed to Coupland (1958) for further information on the impacts of fluctuations in weather upon grasslands and to Section 5.2.1 of this report for impacts of grazing.

4.4 FESCUE GRASS ECOREGION

The fescue grass ecoregion identified by Strong and Leggat (1981), and revised by Strong and Leggat (1992) lies west of the mixed grass ecoregion in a band which parallels the eastern edge of the Rocky Mountains and foothills (Figure 2). It occupies an estimated 1.9% of the province and represents a transition zone between grassland and cordilleran environments.

The main factor affecting the character of this ecoregion appears to be the Cordilleran-based climate that results from the presence of the elevated Rocky Mountains to the west. This ecoregion occurs over a limited area of plains and foothills topography and is generally associated with a portion of the black soil zone. The boundary of the ecoregion is roughly marked by the presence of dark brown soils to the east, and by the eastern and southern limit of aspens (where cover is less than 15%) to the west and north. Natural vegetation patterns in the fescue grass ecoregion have been significantly altered by agricultural practices. Wildlife habitat is largely fragmented, with riparian communities along drainage channels providing the greatest species diversity. Of particular significance are the riparian woodlands of the Oldman and Belly rivers in southwestern Alberta.

4.4.1 Climate

The climate is subhumid continental, created by the mixing of Cordilleran and Prairie climates, and characterized by high annual and diurnal temperature ranges. Frequent chinook winds from the west provide warming and drying trends throughout the ecoregion.

The mean annual temperature for the ecoregion is 5.1°C, with a mean of -3.9°C during the winter and 13.8°C during the summer. Winter temperatures are modified considerably by the influence of the chinooks. However, it is the cooler summer temperatures which appear to distinguish this ecoregion from the adjacent mixed grass ecoregion. There is a considerable irregularity in the frost free period (25 to 110 days) for this ecoregion, due largely to variations in topography and elevation. Similarly, while a mean of 1141 growing degree days (>5°C) is estimated, some areas have as few as 950 growing degree days.

Total annual precipitation is estimated at 445 mm. Rainfall is most abundant during May and June, with drier conditions occurring during the late summer period. Between 30% and 80% of the total annual precipitation may be received as rainfall during the summer. The agroclimatic moisture balance for the ecoregion ranges from -388 to - 126 mm, with a mean value of -294 mm. Winter precipitation totals are typically near 84 cm, a value at least 50% greater than that received in the mixed grass or dry mixed grass ecoregions. However, due to the influence of the Chinook winds, snow depth and cover are comparable to the mixed grass and dry mixed grass ecoregions. A significant variation in precipitation patterns occurs in this ecoregion depending on topography and elevation.

4.4.2 Terrain

The fescue grass ecoregion is located along the boundary of the Western Alberta Plains

and Southern Alberta Uplands physiographic regions of Alberta (Bostock 1970; Pettapiece 1986). Figure 5 and Table 4 outline the specific physiographic subdivisions and associated landform characteristics associated with this ecoregion. There is a considerable increase in elevation from east to west within the ecoregion and terrain may be quite variable, both within and between physiographic subdivisions. Generally draped and ice stagnation morainal deposits dominate the north half of the ecoregion, with an increase in glaciolacustrine materials to the east and a mosaic of glacio-lacustrine, aeolian and dissected morainal deposits over bedrock uplands to the south (Shetsen 1987).

Morainal deposits within this ecoregion are characterized by a variable stone, cobble and boulder component within a mosaic of clay, silt, sand and gravel matrix. The depth of till deposits in the ecoregion varies considerably, from discontinuous and less than 3 m on upland bedrock plains, to greater than 100 m in buried pre-glacial valleys. Accordingly, the terrain conditions throughout the ecoregion vary from nearly level to strongly hummocky, depending on till thickness, mode of deposition and the underlying bedrock topography.

Glaciolacustrine landforms are characterized by considerably lower variations in relief in comparison to adjacent morainal deposits. Often glaciolacustrine plains appear as near level landscapes within a more rolling or hummocky area. The glaciolacustrine materials have been deposited in relatively still waters and are generally sorted. They vary in texture and composition, ranging from coarse sands and gravels to fine clays. Ice-rafted stones are frequently present.

Drainageways associated with the Oldman and Bow rivers and their tributaries are characterized by variable glaciofluvial, stream and slopewash eroded deposits. Deposits of up to 25 m may be expected and bedrock exposures occur in some areas along the drainage channels.

Aeolian deposits are the result of wind action which reworks fine and medium-grained sand and silt materials into longitudinal and parabolic dunes up to 7 m thick. The landscape is undulating to rolling, broken frequently by bands of dune features and scoured, deflation blowout areas.

4.4.3 Soils

Soils are typically of the Black Chernozem great group, characterized by thick, dark topsoil horizons and vegetation cover of mesophytic grasses and forbs and associated grassland-forest communities. Considerable variation in soil development occurs within this ecoregion, however, due to the diversity of terrain, parent material and micro-climatic conditions. Some dark brown soil development is associated with drier conditions along the eastern boundary of the ecoregion while dark grey soils may occur in wetter areas to the west.

The relationship of agroecological resource areas and soils within this ecoregion is illustrated by Table 2. Generally, soils within this ecoregion are loamy to clay loam in texture, with deep, moderately well drained profiles. The ecoregion traverses several agroclimate areas, includ

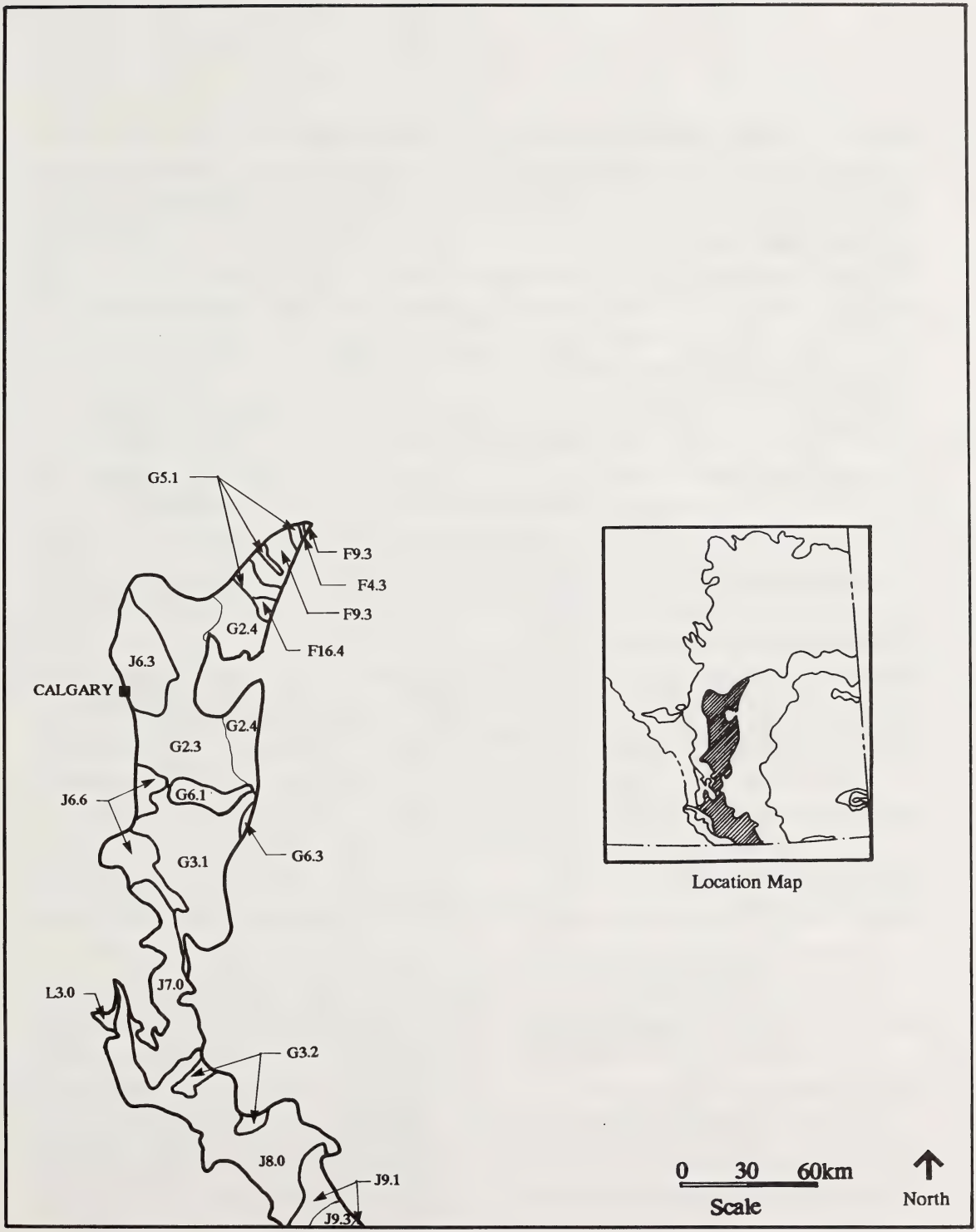


Figure 5. Physiographic Subdivisions of the Fescue Grass Ecoregion.

Table 4. Physiographic Subdivisions of the Fescue Grass Ecoregion.

Section	District	Landform
F. Eastern Alberta Plains		
F4 Bigstick Lake Plain	F4.3 RedDeer Valley	Us-D
F9 Big Rivers Plains	F9.3 Drumheller Plain	GLum.GLvb/Mm
F16 Cooking Lake Uplands	F16.4 Crawling Valley Upland	Mhu
G. Western Alberta Plains		
G2 Olds Plain	G2.3 Rosebud Plain G2.4 Strathmore Plain	Mu.GLvb/Mu(GF) GFu.GFvb/Ru-D
G3 Southwest Plains	G3.1 Little Bow Plain G3.2 Three Rivers Plain	GLvb/Mu.Mu(GF) GFu.GLu.Mu
G5 Drumheller Uplands	G5.1 Delburne Upland	Mh.Mb/Rm
G6 Blackfoot Uplands	G6.1 Gladys Ridge G6.3 Vulcan Upland	Mb/Rm.Mu Mb/Rm.Muh(GL)
J. Southern Alberta Uplands		
J6 Western Benchlands	J6.3 Crossfield Benchland J6.6 Okotoks Upland	Muh.Mbv/Rm-D Mbv/Rm-D.Mu(GL)
J7 Porcupine Hills Upland	J7.0 Porcupine Hills	Mbv/Rvm-D
J8 Cardston Plain	J8.0 Cardston Plain	GLu.Muh
J9 Milk River Upland	J9.1 Milk River Ridge J9.3 Del Bonita Plateau	Mhu.Mbv/Rm-D Ev/Fl
L. Rocky Mountain Foothills		
L3 Southern Foothills	L3.0 Southern Foothills	Mvb.Cv/Rr(R,F)

LEGEND	
Composition (Material)	Surface Expression
E - eolian F - fluvial GF - glaciofluvial GL - glaciolacustrine M - morainal (till) R - rock U - undifferentiated	u - undulating m - rolling h - hummocky r - ridged s - steeply inclined b - blanket v - veneer D - dissected l - level i - inclined t - terraced

ing classes 2AH, 4H-5H, 2A and 2AH-3H and two climate gradients are evident (Pettapiece 1989). Generally, from north to south there is an increase in heat and a decrease in moisture, resulting in limitations of slight moisture and slight heat in the north and slight moisture in the south. From east to west there is a pronounced increase in moisture and decrease in temperature and, therefore, limitations relating to slight moisture deficits occur in the east and severe or very severe heat limitations occur in the west. These lands are rated as Class 3 or poorer, based on climatic limitations. Some Class 2 lands occur along the eastern boundary of the ecoregion, adjacent to the fescue grass and the mixed grass ecoregions.

4.4.4 Vegetation

The following discussion is based primarily upon studies of this vegetation type by Moss and Campbell (1947) and Looman (1969).

Where undisturbed, rough fescue forms large tussocks and dominates the grassland. In the lower, southern foothills Parry's oat grass may be prevalent on shallow soils of rocky and gravelly slopes and where grazing pressure has reduced the extent of rough fescue. At higher elevations, timber oat grass replaces Parry's oat grass, and at still higher elevations and in the northern foothills, Richardson's needle grass becomes the codominant species with rough fescue. Other characteristic species include bluebunch fescue (in southern portions of the ecoregion), western porcupine grass, bearded wheat grass, Hooker's oat grass, low sedge, sun-loving sedge, prairie rose, yarrow, small-leaved everlasting, fringed sage, prairie sagewort, prairie crocus, wild blue flax, harebell, old man's whiskers, sticky geranium, late yellow locoweed, shrubby cinquefoil (south only), and silvery perennial lupine (south only).

The southern portion of the fescue grassland has far greater diversity than the northern, perhaps, as Moss and Campbell suggest, due to its close proximity to a number of other vegetation types, particularly in the mountains (for example, the northwestern U.S. Paloue prairie).

Little of the original fescue grassland remains in an unaltered form, much of it having been grazed or mowed. Mowing tends to decrease the size of rough fescue and on poorer sites, such as stony soil and dry slopes, the amount of rough fescue is decreased at the expense of bluebunch fescue, western porcupine grass, northern wheat grass, june grass, sedges and several forbs. Grazing impacts are discussed in Section 5.2.1 of this report.

Woody species such as shrubby cinquefoil, buckbrush, roses, aspen poplar, saskatoon, and wolf-willow occasionally are found in these grasslands. On moister sites, bog birch and willow may be common, while on drier sites, bearberry and junipers are characteristic. At higher elevations both lodgepole pine and douglas fir may encroach on the grasslands.

Sand dune and sandy outwash vegetation consists of typical fescue grassland species plus wolf-willow or rose and buckbrush shrubs. Spear grasses and sand grass usually increase in dune sites and northern wheat grass becomes more abundant in sand plain areas. Solonetzic soils are

typically occupied by species more characteristic of mixed grass prairie (Achuff et al. 1988).

According to Achuff et al. (1988), wetlands of the northern fescue grassland are transitional between mixed grassland and central aspen parkland types. The most common are wet marshes, characterized by members of the knotweed family, creeping spike-rush and awned sedge. Wet meadows and deep marshes are not common, however the latter may be locally abundant in areas of hummocky terrain and poorly drained sites. Saline wetlands occur most frequently in central and eastern portions of this ecoregion and include species associated with these habitats in the mixed grassland (see Section 4.3.4).

4.5 ASPEN PARKLAND ECOREGION

Aspen parkland has been defined as the co-occurrence of chernozemic black and dark brown soils supporting a mixture of native grassland and forest plant communities in the form of open parkland. This ecoregion is a transitional zone between the grasslands to the south and the boreal forests to the north. Accordingly, it possesses elements of both the boreal and prairie climates, soils and vegetation which combine to form a distinctive character. Presently the aspen parkland ecoregion makes up approximately 7.9% of the province. However, less than 5% of this area still exists as natural habitat (Wallis 1987). Remnant natural parkland tends to occur in those areas least suited for agriculture, such as along drainage channels and in hummocky terrain. These areas constitute an important waterfowl production zone.

4.5.1 Climate

The climate is subhumid to humid continental, created by the mixing of boreal and prairie climates and modified by the mid-Alberta storm track. The major difference between this ecoregion and the grassland-dominated ecoregions to the south is that precipitation is most abundant in July rather than in the spring months of May or June and, accordingly, there is less moisture stress on vegetation in the late summer. This characteristic allows a longer time frame for the implementation of revegetation programs.

The total annual precipitation is 412 mm. The total summer precipitation usually ranges from 234 to 323 mm, representing up to 78% of the total annual precipitation. The summer potential evapotranspiration is substantially less than in other grassland ecoregions, with monthly values of about - 50 mm. Snowfall varies greatly with terrain, elevation and latitude. An ecoregion average of 53 cm annually is similar to that received by the mixed grass ecoregion. However, due to the cooler winter temperatures, less ablation by wind and fewer Chinook winds, snow cover depths and duration tend to be longer in the aspen parkland ecoregion.

High annual and diurnal temperature ranges are typical with average temperatures ranging from 14.4°C in the summer, to - 8.7°C in the winter. The coldest days typically occur in January and February. Extreme cold temperature can reach - 38°C. The mean annual temperature

of 3.3°C is considerably cooler than that occurring in the grassland ecoregions to the south and reflects the influence of the adjacent boreal climate. There is a considerable variation in the frost free period for this ecoregion although it generally exceeds 90 days. Similarly, there is a range of growing season conditions, with a mean of 1257 growing degree days (>5°C).

4.5.2 Terrain

The aspen parkland ecoregion is located in the Alberta Plains physiographic region of Alberta (Bostock 1970; Pettapiece 1986). Figure 6 and Table 5 outline the specific physiographic subdivisions and landform characteristics associated with this ecoregion.

The ecoregion is dominated by undulating to hummocky glacial till deposits, dissected commonly by glaciofluvial channels, streams and slopewash eroded deposits (Shetsen 1990). There is a significant increase in elevation from east to west. The south half of the ecoregion has an increasing proportion of low-relief glaciolacustrine plains, eroded glaciofluvial channels and areas of aeolian deposition. The terrain consists of a complex of glacial landforms which reflect the position of several glacial fronts and ice stagnation blocks during the last glacial period. The landscape is dotted with many glacial features, including: linear landforms which parallel glacial movements (flutes and drumlins); end moraine ridges; hummocky ice stagnation deposits; linear features, such as crevasse fillings, which appear as small elongated ridges and hummocks occurring transverse to ice movement; eskers; meltwater and ice-contact meltwater deltas and fans; and ice-thrust ridges. Drainage is facilitated principally by the North Saskatchewan and Red Deer rivers and their tributaries. A number of lakes and small ponds are also present within the moderate to high-relief landscape.

Glacial deposits are dominated by till consisting of variable stones, cobbles and boulders within a matrix of unsorted clay, silt, sand and gravel materials (Shetsen 1990). The thickness of these deposits is generally less than 25 m on uplands but may reach depths in excess of 100 m in buried pre-glacial valleys.

Areas of glaciolacustrine materials are characterized by relatively low-relief terrain (flat to gently undulating) by comparison to adjacent morainal deposits. The deposits may be up to 80 m thick, with textures ranging from coarse sands and gravels to fine clays (Shetsen 1987, 1990). Ice-rafted stones are frequently present, particularly along the shoreline margins of glacial lake areas.

Glaciofluvial meltwater channels frequently dissect this ecoregion. Typically these landforms are characterized by a range of sediments, including coarse gravels and sands where high velocity flows were dominant, and fine sands, silts and clays where lower-velocity flows were dominant or where meltwater channels entered areas of ponded water. The terrain is variable depending on the size of the channel and the nature of post-glacial erosion. Broad, U-shaped meltwater channels are often characterized by an undulating topography, several terraces or benches along the valley wall, and the presence of a mean

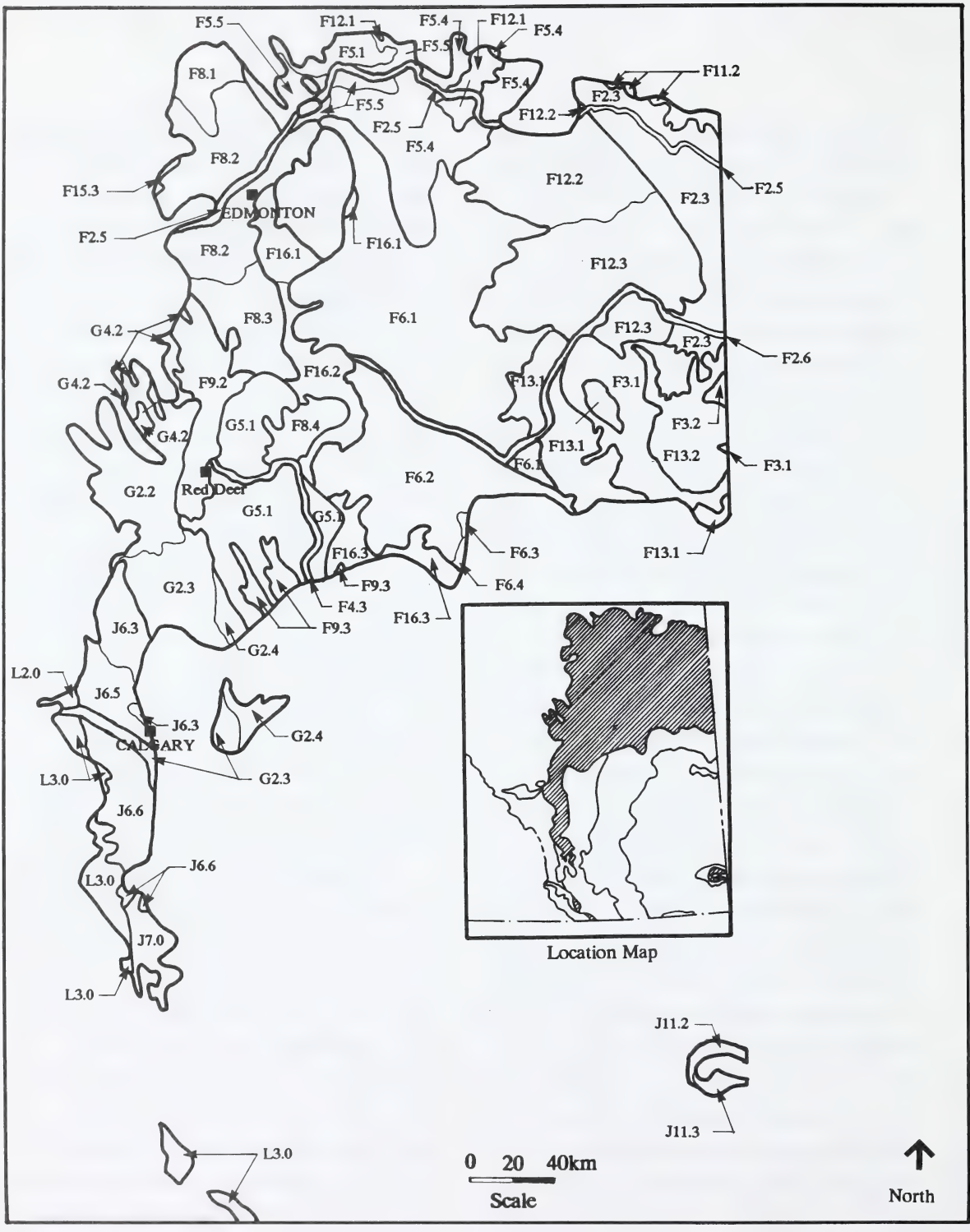


Figure 6. Physiographic Subdivisions of the Aspen Parkland Ecoregion.

Table 5. Physiographic Subdivisions of the Aspen Parkland Ecoregion.

Section	District	Landform
F. Eastern Alberta Plains		
F2 Lac La Biche Plain	F2.3 Elk Point Plain	Mu
	F2.5 North Saskatchewan Valley	Us-D
	F2.6 Battle River Valley	Us-D
F3 Snipe Lake Plain	F3.1 Ribstone Plain	GFu.Er
	F3.2 Dillberry Plain	GFuh.Er
F4 Bigstick Lake Plain	F4.3 Red Deer Valley	Us-D
F5 Tawatinaw Plain	F5.1 Thorhild Plain	Mu(Lv)
	F5.4 Whitford Plain	Mu(GLv)
	F5.5 Redwater Plain	GFuh, GFv/Mu(E)
F6 Sullivan lake Plain	F6.1 Daysland Plain	Mbv/Ru.Mu
	F6.2 Castor Plain	Mbv/Ru.Mu
	F6.3 Sounding Creek Plain	GFbv/Mu.Mu
	F6.4 Berry Creek Plain	Mvb/Ru.Mu
F8 Edmonton Plain	F8.1 Westlock Plain	Mu.Mvb/Ru(GF)
	F8.2 Lake Edmonton Plain	GLu(GF,M,R)
	F8.3 Wetaskiwin Plain	GFuh.GLu.Mu
	F8.4 Buffalo Lake Plain	GFu(M,GL,E)
F9 Big Rivers Plains	F9.2 Ponoka Plain	Mu.GFu
	F9.3 Drumheller Plain	GLum.GLvb/Mm
F11 Thickwood Hills Uplands	F11.2 Frog Lake Upland	Mh.Mb/Rm
F12 Vermilion Uplands	F12.1 Whitefish Upland	Mhu
	F12.2 Myman Upland	Mhu(GF)
	F12.3 Viking Upland	Mhu(GF)
F13 Neutral Hills Uplands	F13.1 Neutral Upland	Mh.Mb/Rm(GF)
	F13.2 Provost Upland	Muh.GFuh.GLu
F15 Cherhill Uplands	F15.3 Glory Hills	GFdh.Mh
F16 Cooking Lake Uplands	F16.1 Beaver Hills Upland	Mhu(GL)
		Mh.Mb/Rm
	F16.2 Bashaw Upland	Mhu
	F16.3 Rumsey Upland	

continued . . .

Table 5. Concluded.

Section	District	Landform
G. Western Alberta Plains		
G2 Olds Plain	G2.2 Medicine River Plain G2.3 Rosebud Plain G2.4 Strathmore Plain	Mu.GLvbMu(GF) Mu.GLvb.Mu(GF) GFu.GFvb/Ru-D
G4 Lodgepole Uplands	G4.2 Bucklake Upland	Mh.Mb/Rm
G5 Drumheller Uplands	G5.1 Delburne Upland	Mh.Mb/Rm
J. Southern Alberta Uplands		
J6 Western Benchlands	J6.3 Crossfield Benchland J6.5 Nosehille Benchland J6.6 Okotoks Upland	Muh.Mbv/Rm-D Mbv/Rm-D.Mh Mbv/Rm-D.Mu(GL)
J7 Porcupine Hills Upland	J7.0 Porcupine Hills	Mbv/Rvm-D
L. Rocky Mountain Foothills		
L2 Central Foothills	L2.0 Central Foothills	Mvb.Cv/Rr(R,F)
L3 Southern Foothills	L3.0 Southern Foothills	Mbv.Cv/Rr(R,F)

LEGEND	
Composition (Material)	Surface Expression
E - eolian F - fluvial GF - glaciofluvial GL - glaciolacustrine M - morainal (till) R - rock U - undifferentiated	u - undulating m - rolling h - hummocky r - ridged s - steeply inclined b - blanket v - veneer D - dissected l - level i - inclined t - terraced

dering channel in the base of the valley. Steeper-sided, V-shaped meltwater channels are associated with stream and slopewash eroded deposits. Present-day channels expose till and bedrock along the slopes of the meltwater channel. The valley sides are prone to local slumping and associated mass wasting processes.

Aeolian landscapes are characterized by fine and medium-grained sand and silt deposits, accumulating to depths of up to 7 m. Longitudinal and parabolic dunes traverse the landscape and are characterized by scour and blowout areas.

4.5.3 Soils

Chernozemic black and dark brown soils of this ecoregion are characterized by a thick, black to dark brown topsoil horizon and a vegetation cover of mesophytic grasses and forbs and associated grassland-forest communities. Considerable variation in soil development occurs within this ecoregion due to the diversity of terrain, parent material and micro-climatic conditions. Drainage is well to moderately well for upland soils and may be imperfect to poor in lowlying and depressional areas. Soil textures of loam and clay loam are common. Modal soil conditions include the presence of deep, organic-enriched topsoil (A) horizons and the soils are well suited to reclamation programs.

The relationship of agroecological resource areas and soils within this ecoregion is illustrated by Table 2. The aspen parkland ecoregion traverses two major agroclimate areas. The eastern portion of the ecoregion is classed mainly as 2AH-3H, with slight moisture limitations and slight to moderate heat limitations. The western and southwestern portion of the ecoregion is classed mainly as 3H, with a moderate heat limitation as the dominant restriction to agricultural land use (Pettapiece 1989). There is commonly an increase in moisture and a reduction in heat to the north and west edge of the ecoregion. The lands within this ecoregion are rated as Class 2 and 3 for agriculture, although areas of better or poorer class lands are present in response to local climate and terrain features.

4.5.4 Vegetation

The following description of the vegetation of the aspen parkland ecoregion is largely derived from Achuff et al. (1988), Bird (1961), and Strong and Leggat (1991, 1992).

On the basis of vegetation patterns, the aspen parkland ecoregion may be subdivided into three main types: groveland, parkland, and willow associations. The groveland subregion is generally present in the drier, southern portions of the ecoregion and is characterized by fescue grassland interspersed with aspen groves. Aspen is found mainly on north-facing slopes, depressional areas and along lower slopes and creek banks. Shrub species such as snowberry, saskatoon, rose, wolf-willow, choke cherry and beaked hazelnut and herb layer with species such as wild lily-of-the-valley, bunchberry and false medic are common in the understory.

The parkland (aspen-dominated) subregion, predominant in the northern and western portions of the ecoregion, is characterized by generally moister conditions and a higher propor-

tion of aspen groves than occurs in the groveland subregion. The presence of occasional balsam poplar, white spruce and paper birch within the groves is indicative of the similarities to the boreal forest ecoregion further to the north. Shrub and tree species composition is similar to that of the groveland, with veiny meadow rue, northern bedstraw, wild strawberry, violets and fireweed common in the herb layer.

Balsam poplar stands occur mainly in the northern portion of this ecoregion, and are frequently found on depressional land forms. Shrubs indicative of the moister conditions include red-osier dogwood, pussy willow, Bebb's willow, bracted honeysuckle and green alder. Tall lungwort, common horsetail, palmate-leaved coltsfoot, sweet-scented bedstraw, bishop's-cap, and baneberry are herbaceous species associated with this vegetation type (Achuff et al. 1988).

Woodlands on sandy soils exhibit stunted aspen poplar and are composed of such understory species as wild red raspberry, roses, snowberry, wolf-willow, creeping juniper, bearberry, sand grass, wild strawberry and blunt-leaved sandwort.

The grassland vegetation of the central parkland areas is very similar to the northern fescue grasslands described in the preceding section (4.4.4). Rough fescue dominates undisturbed sites, with lesser quantities of such plants as spear grasses, sticky purple geranium, northern bedstraw, upland sedges, yarrow, everlasting and asters. On solonetzic soils, western porcupine grass, june grass, western wheat grass and other species more typical of the mixed grass ecoregion predominate.

On north-facing slopes, ravines and in snow accumulation sites, shrubs such as saskatoon, prickly rose, buckbrush, snowberry and silverberry frequently occur.

Willow communities are found commonly throughout the ecoregion and are often associated with the moist, depressional areas within hummocky terrain, and along river terraces. They are particularly evident in the southwestern portion of the aspen parkland, from the Porcupine Hills area to just north of Calgary, and again in the northern portion of the ecoregion.

Open water wetlands and emergent deep marshes are a major feature of the central parkland region. Associated species include awned sedge, spangletop, water sedge, beaked sedge, water parsnip and reed grasses in shallow marshes to wet meadows, and bulrushes and cattails in deeper water. Saline wetlands, often indicated by white, crusty soil conditions, are characterized by such species as samphire, western sea-blite, prairie bulrush, Nuttall's salt-meadow grass, foxtail barley and salt grass.

4.6 MONTANE ECOREGION

The cordilleran ecoprovince is characterized by mountainous terrain with an associated climate determined by the interaction of air masses and high elevations. Within this setting the montane ecoregion occurs as localized zones within the foothills and major valleys of the Rocky Mountains (Figure 2). In total it is estimated to cover only 0.9% of the province. Elevation is apparently an important factor limiting the extent of the montane ecoregion and it typically occurs

below the subalpine ecoregion yet above the fescue grass and aspen parkland ecoregions. It is distinguished from other ecoregions by the occurrence of Douglas fir and lodgepole pine.

The montane ecoregion contains important wildlife habitats, due to the presence of open grassland meadows in close proximity to a variety of other vegetation zones. Montane grasslands provide critical wintering habitat for ungulates such as elk, bighorn sheep and mule deer.

4.6.1 Climate

The extent of this ecoregion represents the cooler end of the montane climatic spectrum. It displays both cordilleran and prairie climatic influences and, at lower elevations and in the eastern-most portions of the ecoregion, an increasingly continental climatic regime. Large annual and diurnal temperature fluctuations, chinook winds and mountain-valley breezes are common within this ecoregion.

Both temperature and precipitation levels vary greatly depending on the nature and elevation of the local terrain. Precipitation totals range from 308 to 1279 mm, with an average of 440 mm occurring annually. Precipitation peaks occur in the spring (May-June) and late summer (August-September), resulting in a mid-summer low. These two peaks in rainfall allow the possibility of initiating revegetation programs during the spring or late summer. However, the nature of the cool climate species would generally favour late summer planting. Summertime rainfall may represent up to 75% of the total annual precipitation. Winter snowfall levels are similarly variable, ranging from 50 to 165 mm with a median of 93 mm.

The ecoregion is characterized by a mean annual temperature of 3.5°C which reflects the influence of warm Chinook winds for much of the winter months. Summertime temperatures of 5.1°C to 18.9°C are typical while temperature ranges of -11.3° to 2.8°C are normal for the winter. The mean summer and winter temperatures are 11.9°C and -5.5°C, respectively.

4.6.2 Terrain

The montane ecoregion is located generally within the Rocky Mountain Foothills physiographic region of Alberta, extending into the lower elevations of the Rocky Mountains to the west, and into the upper elevations of the Southern Alberta Uplands to the east (Bostock 1970; Pettapiece 1986). Figure 7 and Table 6 outline the physiographic subdivisions and associated landform characteristics, generally related to the valleys and low-elevation passes which characterize the ecoregion.

The ecoregion is dominated by a veneer of glacial till or colluvial deposits which mantle the bedrock surfaces of the mountain valleys. Terrain is largely bedrock controlled, with colluvial fans and steep-sided glacial moraines bordering the valley slopes and gently undulating to rolling glacial moraines covering the valley floors. The deposits are highly variable, consisting of angular and subangular stones, cobbles and boulders from local bedrock sources. The matrix is similarly variable, ranging from clays and clay loams to sandy and gravelly materials. Some

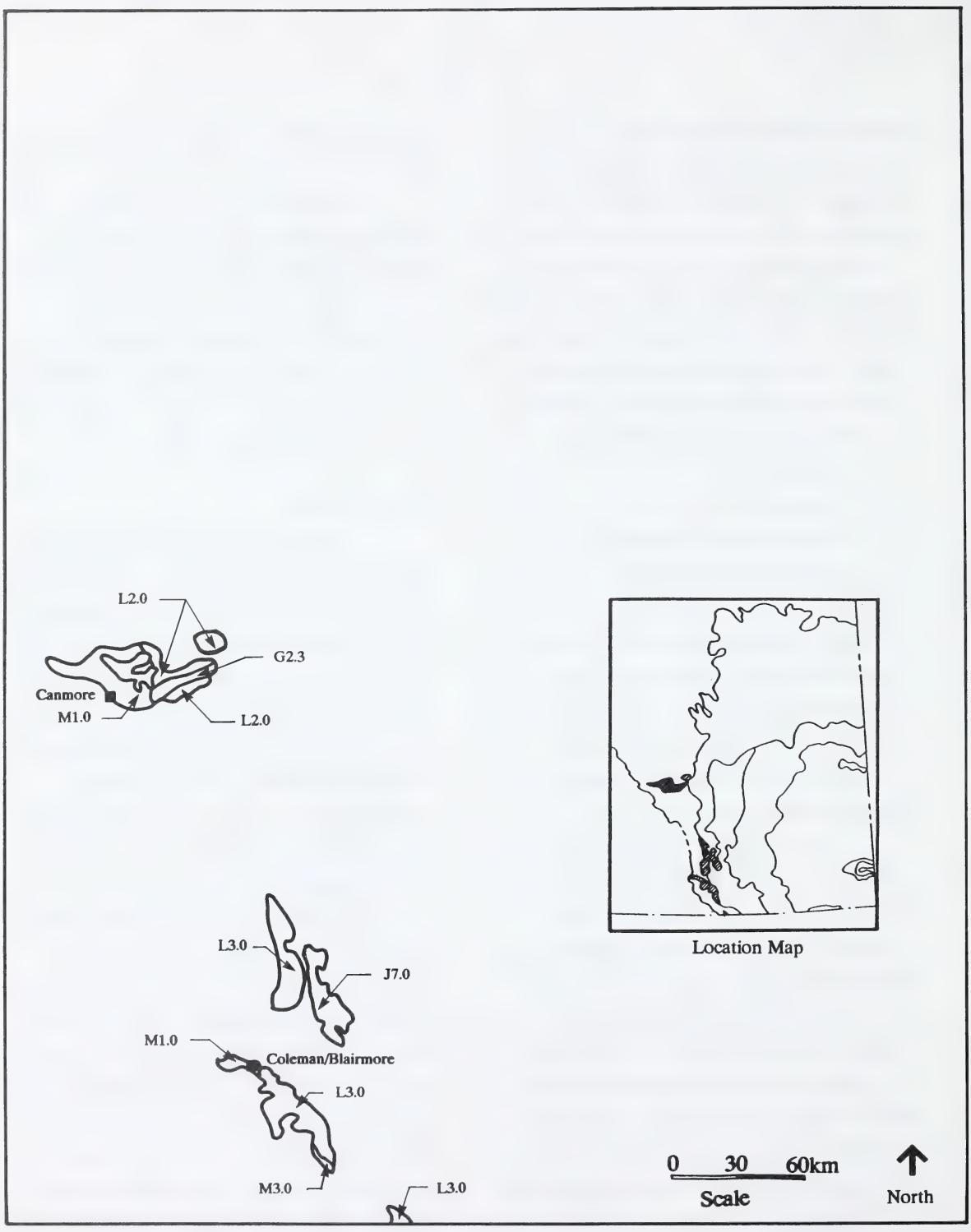


Figure 7. Physiographic Subdivisions of the Montane Ecoregion.

Table 6. Physiographic Subdivisions of the Montane Ecoregion.

Section	District	Landform
G. Western Alberta Plains		
G2 Olds Plain	G2.3 Rosebud Plain	Mu.GLvb/Mu(GF)
J. Southern Alberta Uplands		
J7 Porcupine Hills Upland	J7.0 Porcupine Hills	Mbv/Rvm-D
L. Rocky Mountain Foothills		
L2 Central Foothills	L2.0 Central Foothills	Mvb.Cv/Rr(R,F)
L3 Southern Foothills	L3.0 Southern Foothills	Mvb.Cv/Rr(F,F)
M. Rocky Mountains		
M1 Front Ranges	M1.0 Front Ranges	Cv.Mvb/Rr.Rs.Ff
M3 Border Ranges	M3.0 Clark Range	Cv.Mvb/Rs.Rs.Ff

LEGEND	
Composition (Material)	Surface Expression
E - eolian F - fluvial GF - glaciofluvial GL - glaciolacustrine M - morainal (till) R - rock U - undifferentiated	u - undulating m - rolling h - hummocky r - ridged s - steeply inclined b - blanket v - veneer D - dissected l - level i - inclined t - terraced

areas of rounded outwash gravels and recent fluvial and alluvial deposits occur along existing channels within the montane ecoregion.

4.6.3 Soils

Soil development is highly variable, controlled principally by parent material, terrain and climatic conditions. Soils of the Eutric Brunisol great group are considered modal for well to moderately well drained, predominantly forested sites within the ecoregion. Grey Luvisols may also occur under moderately well drained conditions. Drier grassland areas, typically associated with south-facing slopes and high insolation condi-

tions, are characterized by the development of well to moderately well drained Black Chernozemic profiles. Rapidly drained colluvial or morainal slopes are typically characterized by regosolic soil development. The agroclimatic classification of this ecoregion is 4H-5H to 5H, with severe to very severe heat limitations to agricultural production.

4.6.4 Vegetation

The following discussion of vegetation is derived primarily from Achuff et al. (1988) and Strong and Leggat (1992). The modal vegetation for this ecoregion is considered to be douglas fir; and lodgepole pine and/or aspen forests. Douglas fir forests are found on moderate to steep slopes on colluvial and morainal materials with brunisolic and regosolic soils. On exposed ridges in the eastern part of the ecoregion, douglas fir occurs mainly on shaded north and east aspects. Further into the mountains, it grows on south and west-facing slopes. In closed douglas fir forests, hairy wild rye, pine grass, and low northern sedge are frequently primary herb layer components, with bearberry and snowberry more restricted to southern sections. Other common species associated with douglas fir forests, in the southern part of the province are thimbleberry, mountain maple, purple clematis, birch-leaved meadowsweet, creeping mahonia and glacier lily. Columbian needle grass, bluebunch wheat grass and pine grass are important components of open stands.

Limber pine is another tree species characteristic of the montane ecoregion. It usually is found on exposed rock (frequently sandstone) outcrops and eroding morainal or colluvial deposits. Species frequently occurring in association with the limber pine include bearberry, junipers, northern bedstraw, bluebunch wheat grass, bluebunch fescue, timber oat grass and field chickweed.

Lodgepole pine stands are very common in the Montane, often occurring in association with Eutric Brunisolic or Gray Luvisolic soil types. Common understory species are Canada buffaloberry, green alder, birch-leaved meadowsweet, pine grass, hairy wild rye, wintergreens, prince's-pine and in the south, rattlesnake plantain.

Trembling aspen, balsam poplar and white spruce are additional tree species often found in the Montane. Aspen stands occur on morainal and fluvial landforms such as outwash and alluvial fans, and occasionally on colluvial sites. Balsam poplar stands are situated on floodplains of lower valleys, while white spruce forests occupy gleysols and organic soils along streams and, to a lesser extent, on morainal and colluvial landforms.

Shrubs such as junipers, Canada buffaloberry and shrubby cinquefoil are characteristic of drier conditions, while low-lying areas are dominated by sedges, willows and poplars. Moist shrublands consisting primarily of willows, including basket willow, flat-leaved willow, short-capsuled willow, false mountain willow, and dwarf birch are found along valley bottoms and in seepage areas along slopes. There are few wetlands, however water sedge and beaked sedge are predominant in the marshy areas.

Grasslands tend to be confined to more exposed south and west aspects on colluvial deposits; on alluvial fans and terraces; and on coarse-textured outwash soils of major valleys. Frequently occurring species of these grasslands in the south are rough fescue, bluebunch fescue, oat grasses and bluebunch wheat grass, with reed grasses, northern wheat grass, hairy wild rye, and june grass more prevalent in the north. Northern bedstraw, fleabanes, sages, old man's whiskers and cinquefoils are common throughout.

5. COMMON DISTURBANCE TYPES, EXTENT AND BIOPHYSICAL EFFECTS

5.1 LOCATION AND EXTENT OF NATIVE PRAIRIE REMAINING WITHIN ALBERTA

The location, extent and condition of remaining native prairie within Alberta is not well defined. This was identified as a goal of the Prairie Conservation Action Plan (World Wildlife Fund Canada 1988), specifically expressed in terms of the need to produce an inventory and description of native grasslands within Alberta. Such an information base is clearly fundamental to our understanding of the types and extent of disturbances affecting the native prairie resource at this time.

Various inventories of the grassland and parkland region have been undertaken in the past. These inventories include the Canadian Wildlife Service migratory bird habitat survey, the Canadian Parks Service systems land survey for the prairie region, provincial and regional surveys for potential Ecological Reserves and Natural Areas, (e.g., Sweetgrass Consultants 1988) and the International Biological Program. In addition, Ducks Unlimited Canada has undertaken extensive surveys of mainly wetland prairie habitats. A synthesis of these information sources for the Prairie Conservation Action Plan resulted in a generalized map of the prairie provinces showing the approximate amount of native prairie remaining (World Wildlife Fund Canada 1988). The Alberta portion of this map is shown in Figure 8 with each of the grassland dominant ecoregions superimposed. The relative proportion of remaining native prairie by ecoregion is summarized in Table 7. A review of Table 7 reveals the limited extent of remaining native prairie in the fescue grassland ecoregion while the greatest extent of native prairie remaining occurs within the dry mixed grass ecoregion.

5.2 SURFACE DISTURBANCES

5.2.1 Grazing

The most common use of native prairie grasslands is livestock grazing. Grazing of cattle primarily for beef production occurs on both private and publicly owned land throughout southern and central Alberta. A long history of ranching starting around 1877 to the present has had a significant impact on the nature and condition of Alberta's rangeland. In the period 1900 to 1925, rapid settlement led to considerable cultivation of marginal prairie grassland only to be abandoned during the drought years of the 1930's. In the 1940's, with improved moisture conditions, extensive reseeding of abandoned and severely overgrazed pasture took place with the establishment of grazing leases and community pastures (Adams et al. 1986).

Based on the 1991 census report, Alberta has 6.64 million hectares (16.4 million acres) of rangelands (defined in the census as unimproved lands used for pasture, grazing and hay; Statistics Canada 1991). The distribution of rangeland by ecoregion is reported as approximately 46.5% occurring within the mixed grass prairie, 6.9% in the fescue prairie, 23.1% in the aspen parkland

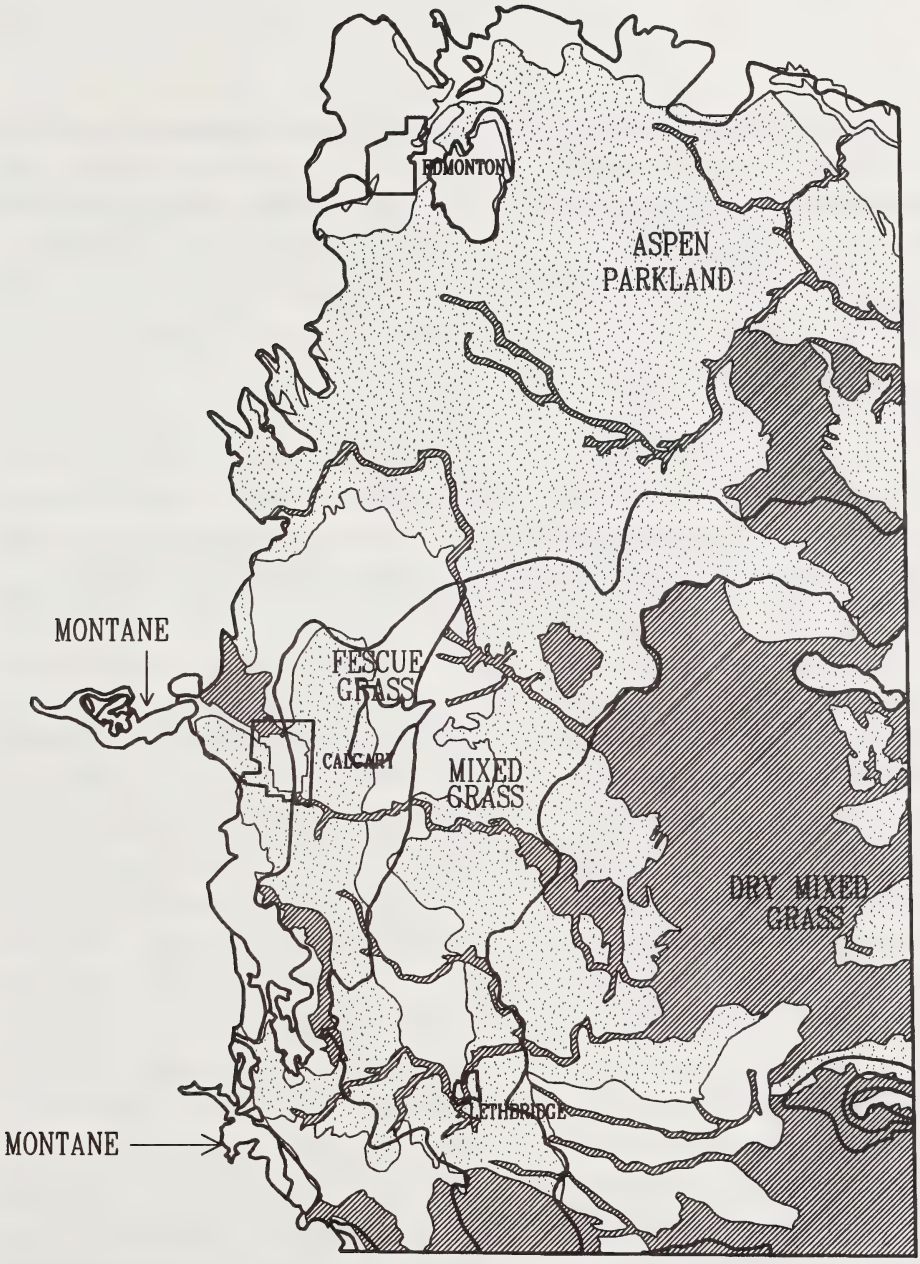


Figure 8. Relative Percentage of Native Prairie Remaining Within the Grassland Ecoregions of Alberta

Legend

- Habitat with less than 10% of the native vegetation remaining
- Habitat with 10% to 50% of the native vegetation remaining
- Habitat with more than 50% of the native vegetation remaining

Scale = 1:3 000 000

Source: World Wildlife Fund Canada (Prairie Conservation Action Plan)

Table 7. Relative Percentage of Native Prairie Remaining Within the Grassland Ecoregion of Alberta.

Ecoregion	Less Than 10% Remaining	10% to 50% Remaining	> 50% Remaining
Dry Mixed Grass*	15	26	59
Mixed Grass	17	57	26
Fescue Grass	38	46	16
Aspen Grass	17	72	11
Montane	0	85	15

* For example, within the Dry Mixed Grass Ecoregion, 15% of the total ecoregion has less than 10% cover of remaining native prairie; 26% of the total ecoregion has between 10 to 50% cover of remaining native prairie and 59% of the total ecoregion has greater than 50% of remaining native prairie.

and 23.5% in the boreal forest (Turnbull et al. 1993). Ownership is primarily public. Various sources indicated the following administrative distribution of rangelands in Alberta, although there is some discrepency between the total area of these lands and that previously reported 1991 census. This variability is attributed to the format underwhich data has been collected by each source.

Under Alberta Forestry, Lands and Wildlife, Alberta Public Lands administers 3.4 million hectares in the "white" (settlement) area of the province and the Alberta Forest Service administers 0.9 million hectares in the "Green" area (Turnbull et al. 1993). Seventeen percent (17%) of Alberta's rangelands, or 1.13 million hectares, are contained within the Special Areas of east central Alberta. These lands are publicly owned native range lands administered by the Special Areas Board. Privately owned rangelands represent 32% (2.15 million hetares) of the provincial total. The remaining 0.6%, or 0.04 million hectares, is administered through the Federal Prairie Farm Rehabilitation Administration.

Grazing is a natural phenomenon, to which grasslands are well adapted. Clarke et al. (1943) and Coupland et al. (1960) stated that the primary factors causing changes in species composition of native grasslands are climate and grazing pressure. Prior to extensive rangeland use, migratory patterns of grazing animals such as bison allowed native grassland to recover before it was over grazed. Our current grazing regimes, however, tend to be more continuous, and often more intensive, allowing little time for recovery of the native plants. As a result, despite the apparent benign use of native grasslands for grazing purposes, the impact of overgrazing on species composition and soil erosion can be severe,

requiring extensive re-seeding and surface treatments to effectively rehabilitate.

The four main grazing systems practised in Alberta are: rotational, deferred, complementary and continuous grazing (Adams et al. 1986). In rotational grazing, different pastures are grazed in rotation, usually with one pasture receiving one or more rest periods per year. In deferred grazing, livestock are kept off a pasture until after the most important forage plants have set seed. This is a commonly used method to rejuvenate depleted range. In complementary grazing, a seeded grass pasture is grazed early in the season, followed by grazing of the native pasture. Continuous grazing involves uninterrupted access to a pasture, often for a set period of time, e.g., winter or summer.

The effects of grazing on native rangeland may be summarized as follows:

1. effects on the individual plant
2. effects on the plant community
3. effects on litter
4. effects on soil and soil micro-organisms

5.2.1.1 Effects of Grazing on the Individual Plant. Individual plant response to grazing is related to site and climatic conditions, palatability, morphology, phenological stage, competition from other plants, intensity of grazing, and grazing history (Saskatchewan Agriculture Development Fund n.d.).

The ability of any plant to recover from grazing involves both the re-establishment of photosynthetic tissue and the ability to retain a competitive position in the plant community (Caldwell 1984). Some plants, (for example wheat grasses, blue grama grass, and needle-and-thread) may shift from a tall, upright growth form to a shorter, more prostrate habit as a defensive response to long-term grazing (Romo and Lawrence 1990).

Individual species are classified as decreasers, increasers or invaders based on their response to increased grazing pressure. Decreasers are plant species of the original or climax vegetation that will decrease in relative amount with continued overuse. Usually they are the most desirable plants on the range. Increasers are plant species of the original vegetation that will increase initially in relative amount with increased grazing pressure. They are normally less palatable and less productive than decreasers. Invaders are normally non-native plants that encroach as decreaser and increaser plants are weakened by heavy grazing. Invaders are absent or present in low proportions in the climax vegetation (adapted from Adams et al. 1986 and Saskatchewan Agriculture Development Fund n.d.).

Beneficial effects of grazing on plants include: (1) removal of older tissue, which is less efficient in photosynthesis than younger tissue; (2) increased light availability to lower, younger tissue; (3) increased stomatal resistance, which promotes water conservation; (4) increased forage production due to compensatory growth; (5) recycling of nutrients contained in animal waste; (6) speeding senescent forage breakdown by trampling; and (7) creation of favourable microsites in

hoofprints for seedling establishment, especially on hard packed, well-drained soil (Saskatchewan Agriculture Development Fund, n.d.).

Grasses are well-adapted to grazing because usually their growing point is at or below the soil surface and is therefore not removed by grazing animals. The effects of defoliation on a grass tiller depends on the species, season, intensity, frequency and duration of the defoliation event (Vallentine 1990). Reece et al. (1988), in Nebraska, noted that short-duration grazing (an intensive form of rotational grazing) increased the numbers of tillers per plant but generally reduced the mean weight of the tiller in bunchgrasses. Some defoliation may stimulate greater growth, similar to pruning of trees or shrubs (Trottier 1992).

The effect initially observed on heavily grazed plants is a decrease in density, vigour and productivity of the principal forage plants. Overgrazing depletes carbohydrate reserves which the plant needs for winter survival, early spring growth and growth after defoliation (Saskatchewan Agriculture Development Fund n.d.). When an area is overgrazed, plant root volume and depth decrease as there is insufficient leaf area to produce food reserves for root growth. Roots of heavily grazed plants therefore tend to be shorter, sparser, and more concentrated in the top part of the soil profile (Vallentine 1990). Grass roots stop growing after severe defoliation and do not resume growth until the grazed leaf material is replaced. This reduces the competitive ability of the plant and it becomes more prone to environmental stresses such as temperature extremes and lack of moisture (Romo and Lawrence 1990). Continuously cropped plants become less drought resistant and eventually die (Trottier 1992).

Results of studies by Willms et al. (1986) in Alberta suggest that dormant season grazing would have no negative effect on forage yield in fescue prairie but rather might enhance plant vigour by stimulating tillering in grasses. Forbs, mainly prairie sage, could take better advantage of conditions presented by the redistributed litter than could grass. In the mixed prairie, grazing during dormancy might be expected to reduce forage yields as a result of removing dead plant litter.

5.2.1.2 Effects of Grazing on the Plant Community. In general, as grazing pressure increases, less productive, less palatable subdominant species in the community increase and species composition shifts from taller grasses to shorter grasses as soil conditions change. A possible additional impact on the vegetation community may occur where tame hay is fed to grazing livestock, resulting in the introduction of non-native species.

In mixed grass prairie, there will be a shift in species composition to favour short, rather than mid height grasses, and sedges. Heavy grazing of wheat grass dominated communities will cause an increase in the relative abundance of blue grama grass in relation to mid grasses and of needle-and-thread in relation to western porcupine grass. Generally, grazing on the Canadian mixed prairie decreases the basal area of spear grasses and wheat grasses, increases blue grama

grass and sedge species and has erratic effects on june grass (Coupland et al. 1960). Weedy species such as fringed sage, moss phlox, broomweed and thread-leaved sedge will increase (Campbell et al. 1962; Coupland et al. 1960).

In the dry mixed grass ecoregion (formerly short grass ecoregion), studies by Clarke et al. (1943) and later, Campbell et al. (1962), indicated that increased grazing pressure resulted in a decrease in total grass cover, a decrease in needle-and-thread, and in some areas western wheat grass, and an increase in blue grama grass, Sandberg's blue grass, june grass as well as forbs such as fringed sage, moss phlox and prairie selaginella. Damage by rodent and insect pests was often exacerbated by heavy grazing. Clarke et al. (1943) suggested that climate played a very important role in these changes in their study, which was conducted during the drought years of 1929 to 1939.

With increased levels of grazing in Alberta's fescue prairie, Moss and Campbell (1947) noted an increase in the abundance of Idaho or bluebunch fescue and Parry oat grass in relation to rough fescue. Rough fescue became quite patchy, tending to persist on moister situations and where protected by shrubs from grazing (Moss and Campbell 1947). On better sites rough fescue was largely replaced by bearded wheatgrass, while june grass, Hooker's oat grass, western porcupine grass and timber oat grass became fairly common. On drier sites, slender wheat grass became less common than june grass, spear grasses, bluebunch fescue, Parry oat grass, northern wheat grass and bluegrass species. The upland sedges, shrubs and certain forbs became abundant under grazing. Overgrazing soon reduced or eliminated rough fescue while various other species increased. In some cases, low sedge became the dominant plant. In other areas, there remained only sparse cover of sedges, fringed sage and pussytoes. Further overuse resulted in an increase in abundance in species of the mixed prairie such as needle-and-thread, blue grama grass and western wheat grass (Moss and Campbell 1947).

Looman (1969), in studies of fescue grasslands throughout western Canada, reported a decrease in rough fescue and an initial increase in oat grasses with grazing. However, as grazing pressure intensified, oat grasses decreased. There was a corresponding increase in sedges on drier sites and Kentucky blue grass on wetter sites. He noted that floristic composition became poorer with moderate grazing and that common invaders on overgrazed fescue prairie were timothy and smooth brome grass.

More recent studies on the fescue grassland of southwestern Alberta (Willms et al. 1985, 1988) produced similar results. Heavy grazing on fescue grassland decreased rough fescue, and initially increased Parry oat grass. As grazing increased, Parry oat grass declined and competitive advantage shifted to the shorter and less palatable forbs and sedges. There was higher production of weeds such as fringed sage, locoweed, pussytoes and dandelion, and bare ground also increased.

Retrogression in the species composition caused by overgrazing occurs rapidly, but suc-

cession following rest from grazing, is slow. The rate of retrogression and succession depends on the plant species and grazing pressure.

Corollary studies by Dormaar and Willms (1990) showed that overgrazing of rough fescue prairie resulted in shorter, shallow-rooted, less productive species that were more resistant to grazing.

Heavy or overgrazing, particularly by sheep and goats, may decrease the shrub component of the plant community. Changes due to overgrazing are exacerbated by conditions such as low rainfall, high evapotranspiration potential and low water yields (Antevs 1952; Branson 1975).

5.2.1.3 Effects on Litter. Litter is the accumulation of undecomposed organic matter on the soil surface. It helps to conserve moisture by insulating the soil against solar radiation, thereby reducing temperature, light and evaporation at the soil surface (Hopkins 1954; Weaver and Rowland 1952; Willms et al. 1986). Some removal of litter by grazing may have beneficial effects. For example, light to moderate grazing controls organic matter buildup. Also trampling breaks down dead plant material and exposes the soil seedbed (Trottier 1992). Langer (1963) has suggested that removing litter will allow more sunlight penetration and therefore more tillering.

However removal of litter by grazing may lead to increased wind and water erosion. In dry sites, loss of litter might produce a moisture deficit because infiltration of rainfall is less deep, soil temperature is higher and roots are nearer to the soil surface than in more mesic sites (Willms et al. 1986).

Results of studies carried out by Willms et al. (1986) in fescue and mixed prairie implied that dormant season grazing would not have a detrimental effect on forage yield in the fescue prairie and might promote plant vigour by stimulating tillering in grasses. Grazing during dormancy in the mixed prairie, however, might be expected to reduce forage yields because of loss of standing dead plant litter.

Heavy grazing in the fall can deplete standing litter which traps snow in the winter, therefore resulting in drier soil conditions. These drier soil conditions may result in a transition to more drought adapted plant species in the plant community.

5.2.1.4 Effects of Grazing on Soil and Microorganisms. Soil response to grazing pressure tends to be more gradual than either plant response or community composition changes. Grazing may, in some cases, decrease soil moisture, decrease aeration through compaction, and decrease litter accumulation (Trottier 1992).

Depletion of vegetation cover exposes more bare soil to wind or water, and when the infiltration capacity of the soil is reduced by compaction, runoff and erosion rates are normally increased (Antevs 1952; Branson 1975). Increased bulk density and a reduction in hydraulic conductivity, coupled with the loss of vegetation, also leads to an increased potential for severe runoff and erosion (Dormaar et al. 1989). Loss of

herbaceous cover due to overgrazing could also result in increased formation of soil crusts and loss of favourable microsites necessary for germination and establishment of grass seedlings (Winkel et al. 1991). Erosion caused by poor grazing practices will be prolonged and accelerated by continued land abuse.

Pioneering studies of grazing impacts on dry mixed grass prairie by Clarke et al. (1943) indicated an increase in wind and water erosion as a result of overgrazing. It appeared that the forbs and shrubs which increased on depleted pastures were not as effective at binding soil as were the grasses. Trampling compaction, with a subsequent decrease in moisture absorbing capacity, increased the rate of water loss due to runoff and evaporation.

In a study of the fescue grassland in the Porcupine Hills, Willms et al. (1988) noted that soil organic matter, carbohydrates, and depth of topsoil (Ah horizon) were significantly greater on ungrazed patches but that nitrates and ammonia along with available phosphorus were greater on overgrazed patches. They suggested that overgrazing will favour shallow-rooted plants which might alter soil organic and inorganic constituents and perhaps depth of soil by reducing the amount of organic matter added.

In a study of the grassland interface between fescue and mixed grass range northwest of Ft. MacLeod, Dormaar et al. (1989) noted that the soil was black in the grazing exclosures and dark brown in the grazed sections, suggesting that either there was a loss of organic matter; or differential rates of organic matter and/or decomposition between grazed and rested treatments. Soil moisture was found to be higher in the exclosures, soil bulk density increased with grazing pressure, and hydraulic conductivity decreased with grazing. Fungal biomass as well as the carbon and nitrogen content of the soil decreased significantly under increased grazing pressure.

Studies by Dormaar and Willms (1990), in the fescue grassland of southwestern Alberta, showed that overgrazing resulted in the reduction of organic matter and loss of soil structure which, in turn, contributed to surface sealing, reduced infiltration rates, and presumably higher evaporation. Eventually the soil changed to that of a drier microclimate, associated with warmer temperatures in the summer.

Livestock activity can affect the water-intake characteristics of the soil (Johnston 1962) by removing cover and compacting the soil. As grazing intensity increased, both water-holding capacity and water intake increased. Increased runoff resulted from reduced infiltration and water-holding capacity. Similarly in a study of the grazing impacts on soil water in mixed prairie and fescue grassland ecoregions in Alberta, soil water was generally reduced at all depths by grazing with differences between the controls and the grazed treatments being less pronounced at 0 to 30 cm than at greater depths (Naeth et al. 1991a). Heavy intensity and/or early season grazing had more impact on soil water than light intensity and/or late season grazing. Predicted higher amounts of soil water late in the growing season due to reduced evapotranspiration from heavily grazed vegetation compared to lightly grazed

vegetation was not evident; rather higher infiltration rates appeared to compensate for higher evapotranspiration (Naeth et al. 1991a). Soil bulk density also increased with increased grazing, although this was ameliorated to some extent by frost action over winter (Dormaar and Willms 1990; Thomas 1960).

Increasing the grazing pressure resulted in a higher excreta load, which together with increased bulk densities and decreased water-intake characteristics may have serious consequences for surface water quality. Total soil nitrogen (N) content increased with very high grazing pressure even though total N in the topsoil remained the same. The grazing had caused a redistribution of N in the soil by concentrating a greater proportion in a shallower topsoil. Based on these findings, Dormaar and Willms (1990) recommended that plants should not be grazed too early in the spring when they are mobilizing resources for growth, and a 50% carryover of current production should be allowed from year to year. This carryover provides emergency forage but more importantly, sustains the nutrient status and hydrological properties at an optimum level, thereby stabilizing annual production (Dormaar and Willms 1990).

A number of studies have illustrated that very heavy grazing of fescue grassland changed the colour of the topsoil from black to dark brown, raised the pH, reduced the percentage of organic matter and percentage of total P, but increased $NaHCO_3$-soluble P and soil temperature. Total N remained the same, but carbon:nitrogen ratios decreased. Soil moisture decreased with increased grazing intensity as water intake rate was reduced and, evaporation likely increased with the removal of litter from the surface. The potential for soil erosion by water is high when about 15% (or more) of the surface is bare (Dormaar et al. 1990).

The effects of reduced organic matter and topsoil loss from overgrazing are severe on the soil biota. The diversity and amount of soil microfauna required for effective mineralization vary directly with soil depth and organic matter. A similar relationship exists with soil nitrogen. Some researchers have assumed that lower herbage yield can result in loss of diversity in the soil biota and therefore reduced rates of important soil processes (Whitford 1988).

5.2.2 Fire

The role of fire in the natural ecology of native prairie grasslands is an important one both in terms of successional processes and as a tool in range management. This type of surface disturbance, while not central to the theme of native grassland reclamation and restoration is addressed in the form of a separate background data report presented in Appendix I. A discussion is provided on the response of prairie grasslands to fire, the effects of fire on plant and animal species, the response of the soil resource to fire, as well as a description of selected grasslands which have been described in terms of their development following fire events.

5.2.3 Recreational Land Use

A wide variety of recreational land use activities are possible within the prairie grasslands of Alberta including hiking, riding, touring, picnicking, big game and upland bird hunting, as well as more general wildlife viewing and aesthetic appreciation. As to how these activities may impact areas of native grasslands, little is known about the degree or extent of such disturbances.

The principle kinds of impacts associated with recreational land use in grassland ecoregions are related to surface disturbance such as those resulting from off-road vehicle use, trails or other activities which can damage vegetation, compact soils and lead to increased wind and water erosion. The resulting increase in bare soil and the decrease in infiltration rates on compacted soils may increase runoff, surface erosion and downslope sedimentation of disturbed areas. Where areas are designated or accessible for recreational land use it is difficult to restrict trail use. Accordingly, it is important that native grassland areas be protected from uncontrolled use, particularly where vehicular access is permitted, through adequate signage and educational programs.

Reclamation of areas affected by trail braiding and associated erosion is difficult, particularly in semi-arid grasslands where the process is constrained by low moisture levels. Compaction of soils and reduced infiltration appear to be the most important impacts, requiring mechanical scarification to improve moisture infiltration, and re-seeding to reestablish the original vegetation cover (Cannon and Landsburg 1990; Schuler and Lowery 1986).

5.2.4 Powerlines

In 1981 there were approximately 155 824 km of power lines in Alberta, most of which occur within the White Area of the province (Webb 1982). Transmission lines are categorized according to the voltage they carry: transmission lines (over 60 kV) accounted for 15 596 km of the total; subtransmission and distribution lines (60 kV or less) for 61 435 km; rural electrification area lines for 67 748 km; and, utility owned farm lines for 11 045 km (ERCB 1982). A summary of the extent of transmission lines found within each of the grassland ecoregions is presented in Figure 9 and Table 8. Table 8 reveals that a large proportion of the higher voltage lines (240 kV and greater) are concentrated with the fescue grassland ecoregion and in the western margins of the Aspen Parkland (Calgary - Edmonton corridor). Lower voltage lines (138 kV and less) occur throughout the aspen parkland, mixed grass and central portion of the dry mixed grass ecoregions (Figure 9). The proportion of those lines traversing native prairie has not been determined; however, such information would be useful in assessing the extent of disturbances at a more detailed level.

Most of the power lines in Alberta that follow road allowances do not adversely affect Alberta's agricultural land base, which has been the major area of concern and focus regarding the impact of transmission lines. To this end, mitigation has largely been devoted to avoiding the crossing of agricultural land or in reducing the impacts, costs and hazards to farmers, for

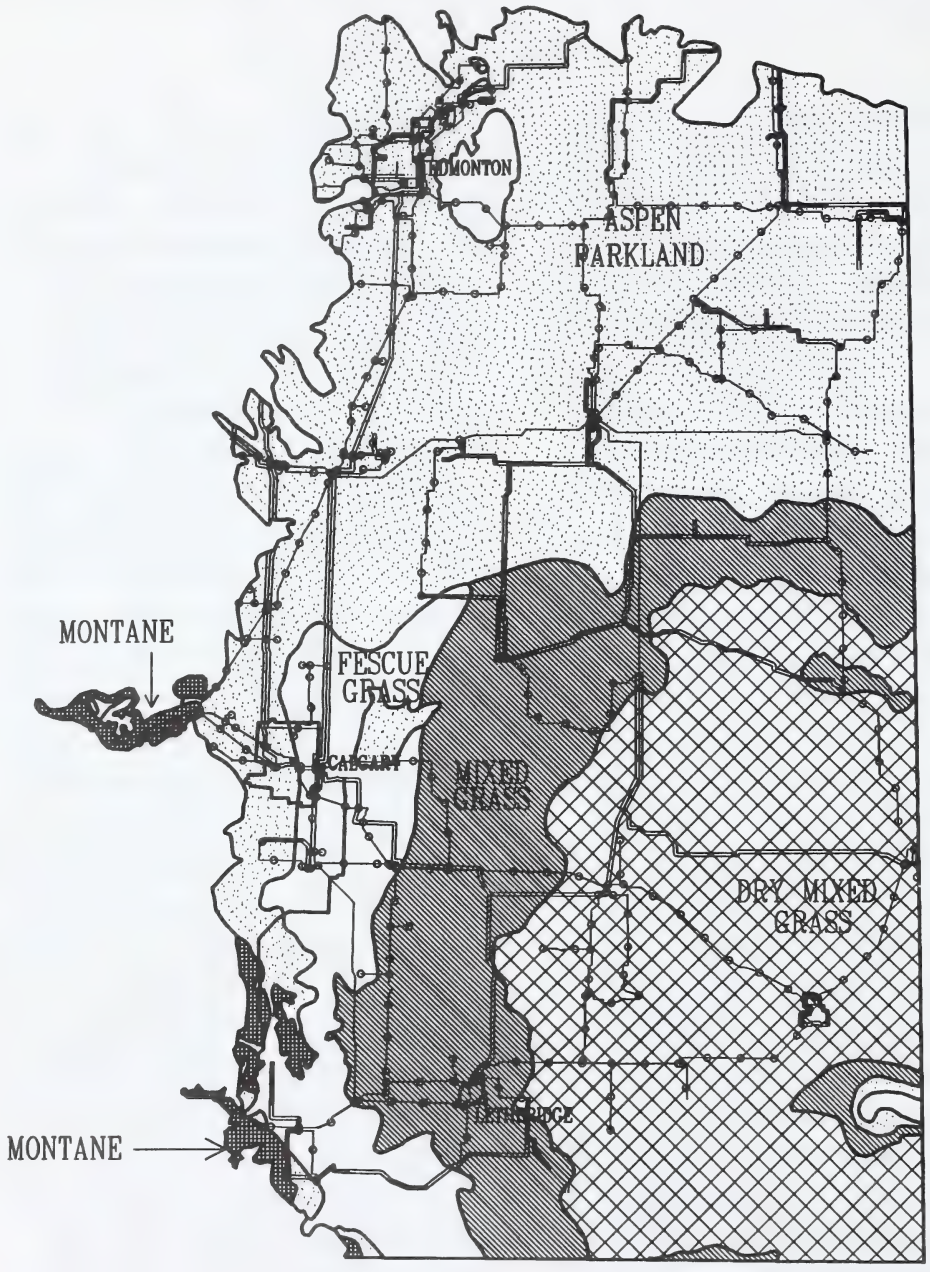


Figure 9. Extent of Electrical Transmission Lines Within the Grassland Ecoregions of Alberta

Legend

72kv — 240kV

138kv — 500kV

Scale = 1:3 000 000

Source: ERCB, January 1991a

Table 8. Extent of Electrical Transmission Lines Within the Grassland Ecoregions of Alberta (kilometres).

Ecoregion	Transmission Line Operating Voltages (kV)				
	500	240	138	72	Total
Dry Mixed Grass	0	278.17	789.58	146.55	1 214.3
Mixed Grass	0	301.78	663.03	415.04	1 379.8
Fescue Grass	99.29	304.62	393.19	161.77	859.6
Aspen Parkland	37.91	1087.47	2337.18	683.63	4 208.3
Montane	50.32	0	160.74	9.80	270.5

Source: Energy Resources Conservation Board (ERCB) 1991a.

example, by replacing standard above ground lines with subsurface lines.

There is a lack of specific information on the environmental impacts resulting directly from the installation and maintenance of power lines within a prairie grassland context. Research in this area is largely concerned with vegetation management of trees and shrubs (Campbell and Associates 1990). Little research has been conducted on the effects of construction on vegetation composition, successionally induced vegetation change or surface compaction on native prairie soils.

Soil compaction associated with construction and maintenance operations on rights-of-way is nevertheless a common problem for managers and landowners. Studies on soil compaction carried out in agricultural settings show that crop yields may be reduced by 10% to 20% of normal (Steinhardt et al. 1987). Such studies also show that freeze-thaw and wetting-drying cycles reduce the effects of soil compaction slowly over time but only where adequate soil moisture is present. The duration of damage has been found to be 3 to 5 years, with the extent influenced by the growing season, weather and soil conditions (Byrnes et al. 1982). Crop yields may however be unaffected if rainfall is plentiful and well-distributed over the growing season (Steinhardt et al. 1987).

In a study which compared vegetation cover and composition on utility rights-of-way between semi-arid and arid environments, results showed that the semi-arid site recovered more quickly. This was attributed to the fact that the adjacent native species also made-up the pioneer species which readily recolonized the disturbed site. In the desert environment, pioneer species were not present in the climax desert environment which existed on either side of the utility corridor, and natural recovery was much slower (Walker et al. 1986).

Several recommendations have been made to reduce the impact of soil compaction on rights-of-way (Steinhardt et al. 1987):

1. control traffic on rights-of-way to reduce the area of soil which will be compacted;
2. limit size of equipment, where possible, and reduce the contact pressure on the soil surface;
3. keep operations to a minimum when soil moisture is near field capacity; and
4. restrict traffic to areas insulated with surface organic debris.

Where vehicle use has led to vegetation damage and soil compaction, natural recovery seems to be the most common method of prairie restoration.

5.3 SOIL DISTURBANCES

Native grasslands within the dry mixed grass and the mixed grass ecoregions may be affected adversely by even small-scale surface disturbances such as wellsite development. These ecoregions are characterized by low precipitation and high evapotranspiration. The landscapes associated with native grasslands range from steeply sloping valley and coulee complexes to nearly level upland plains. Soils are typical of the brown to dark brown zone and are frequently characterized by poor topsoil development, low organic matter, soil moisture and soil fertility. Sandy, solonetzic and alkali soil conditions are also often present. The vegetation cover within native grassland areas may be sparse and, accordingly, disturbed sites are very susceptible to erosion (Toogood and Cairns 1973). These factors significantly increase the difficulty of successful reclamation following wellsite development.

Native grasslands within the fescue grass and aspen parkland ecoregions are generally characterized by higher precipitation and lower evapotranspiration levels than the dry mixed grass and mixed grass ecoregions. The landscapes associated with native grasslands range from steeply sloping valleys and escarpments to nearly level upland plains. Soils are typical of the dark brown and black zones and are characterized by relatively deep topsoil development, moderate to high organic matter content and adequate soil moisture. Sandy, solonetzic and alkali soil conditions may be present in some areas. The vegetation cover within native grassland areas is generally abundant but may be prone to erosion if the protective vegetative cover is removed. However, with the implementation of adequate environmental protection measures during construction and operations, reclamation is generally successful (Naeth 1986).

5.3.1 Oil and Gas Wellsites

There are approximately 109 600 wellsites within the grassland ecoregions of Alberta (ERCB 1991b). Their distribution within these ecoregions is presented in Figures 10 and 11 (active and abandoned, respectively) and summarized in Table 9. Table 9 reveals the dominant concentration of both active and abandoned wells within the dry mixed grass and aspen parkland ecoregions. In proportion to the areal extent of each eco-

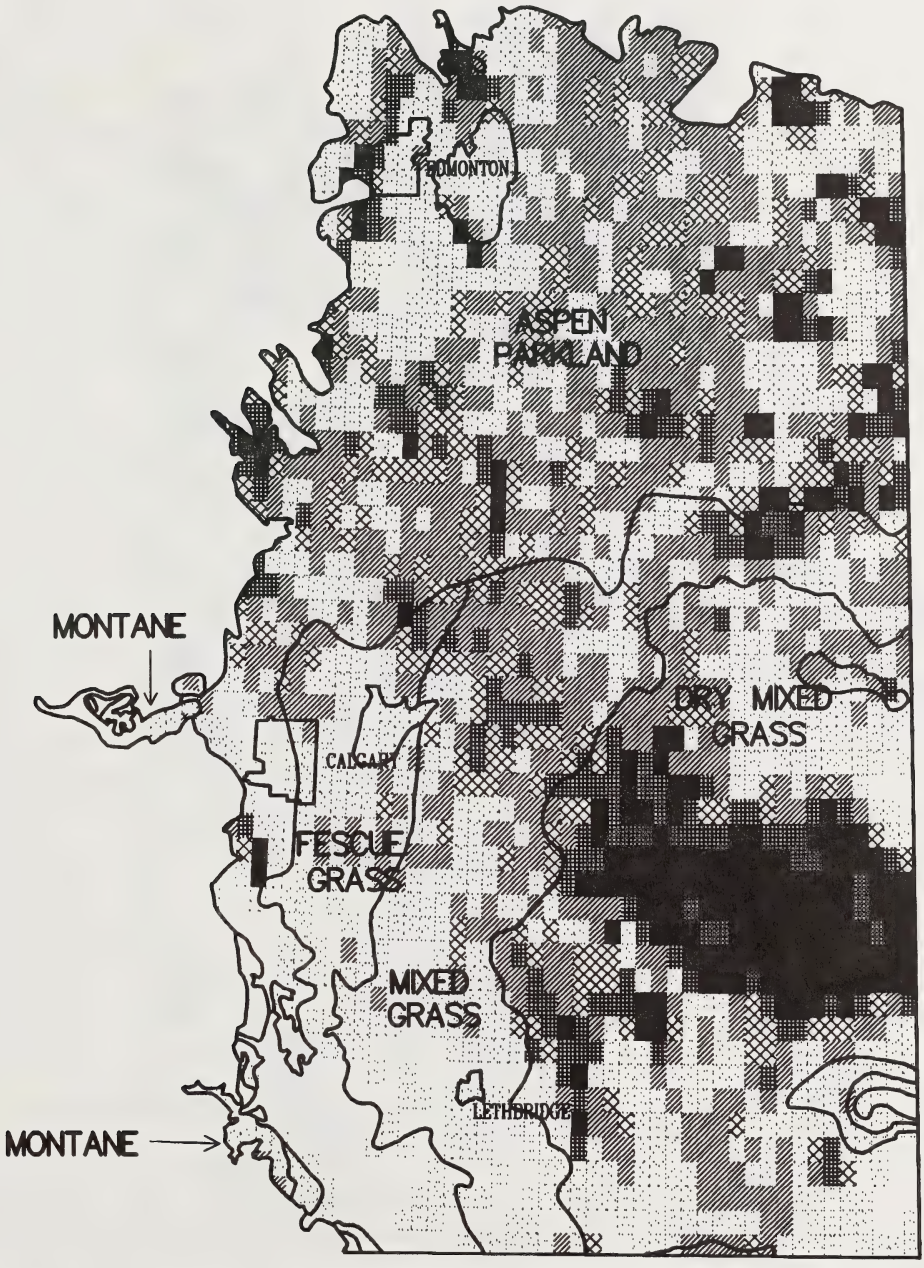


Figure 10. Distribution of Active Oil and Gas Wells in the Grassland Ecoregions of Alberta

Legend

0	26-50
1-10	51-100
11-25	> 100

Scale = 1:3 000 000

Source: ERCB, January 1991b

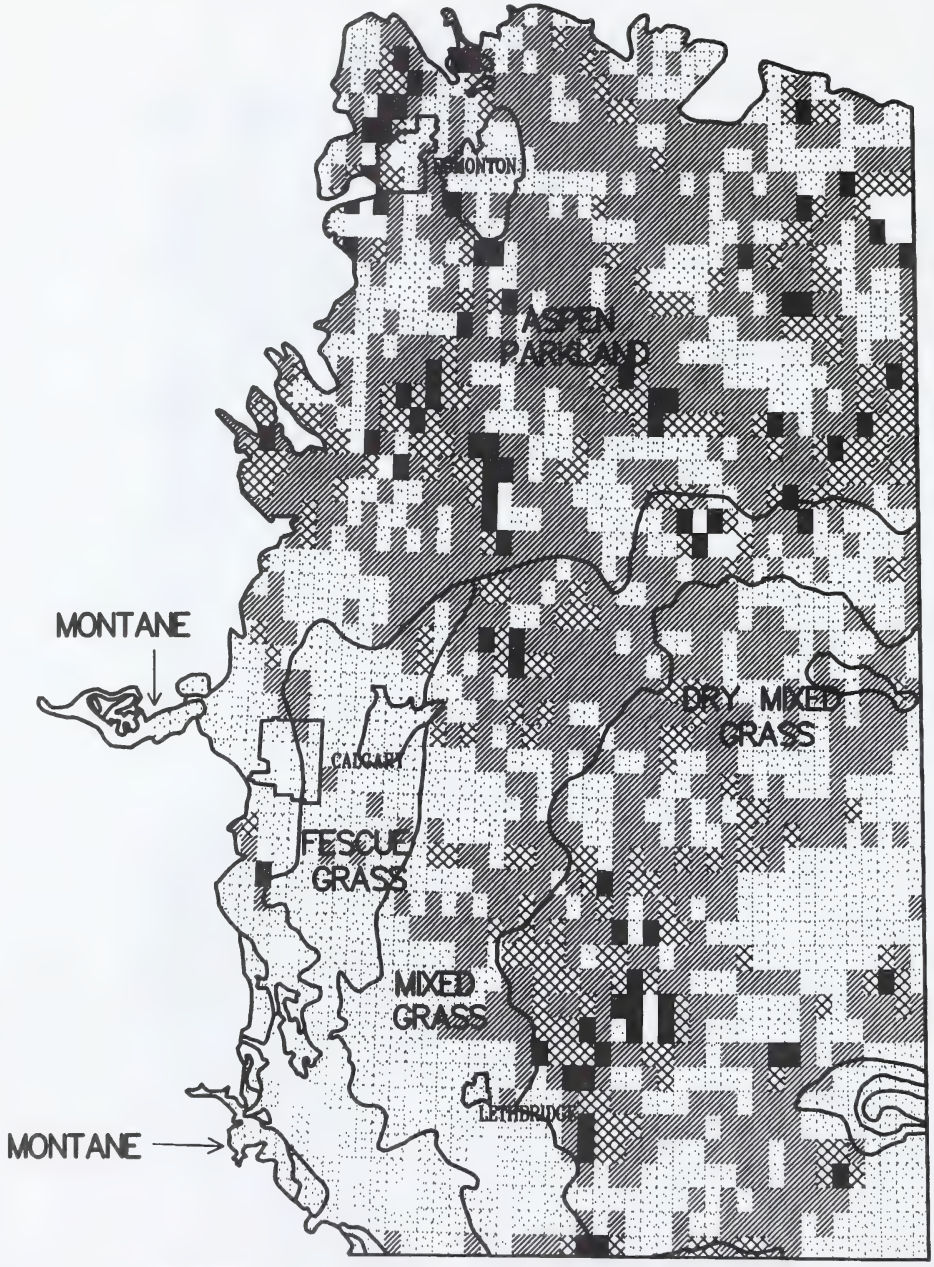


Figure 11. Distribution of Abandoned Oil and Gas Wells in the Grassland Ecoregions of Alberta

Legend

0
1-10
11-25
26-50
> 50

Scale = 1:3 000 000

Source: ERCB, January 1991b

Table 9. Number of Active and Abandoned Wells Within the Grassland Ecoregions of Alberta.

Ecoregion	Active Wells	Abandoned Wells
Dry Mixed Grass	30 556	10 473
Mixed Grass	8 378	6 814
Fescue Grass	1 716	1 297
Aspen Parkland	29 131	20 928
Montane	171	141
TOTAL	69 952	39 653

Source: ERCB 1991b

region, the fescue grassland and montane ecoregions have a relatively small number of wellsites. While Table 9 reveals the gross location of wellsites by ecoregion, the extent of disturbance to native grassland remains unclear. The next step in this evaluation would be to compare the number of wells located on native prairie versus agricultural land. Such an information base would be useful in terms of assessing those types of prairie grasslands subject to greater or lesser development pressure from oil and gas exploration and production. This would allow a relative risk assessment to be assigned to particular native prairie grasslands subject to wellsite disturbance.

Oil and gas wellsites occurring within native grasslands typically consist of a cleared, sometimes bermed area of land which contains the well and associated infrastructure. The biophysical disturbances typically associated with wellsite access and development include vegetation removal, grading, topsoil stripping and storage, and subsoil compaction. Additional impacts may include sump excavation and disposal. If spills or leaks have occurred, both surface and subsurface contamination may also be present.

A number of development and reclamation procedures implemented during the construction and operation phases of wellsites in native grassland areas can significantly aid in reducing environmental impacts (Special Areas Board et al. 1992).

1. Wellsites, and related access road and pipeline infrastructure, should be located such that a minimal area will be impacted by the development. Multiple well drilling pads, directional or slant hole drilling should be considered to reduce the extent of environmental disturbance. The least environmentally sensitive area that meets technical requirements should be selected for wellsite development.
2. Relatively level sites should be chosen to minimize the amount

of cut and fill activities and the size and shape of the site should also be modified to reduce the disturbance to surface terrain. Grading should only be considered if a reasonably level site cannot be located. Areas such as steep slopes, coulees, wetlands, river benches, dry lake beds and riparian areas should be avoided. Topsoil and vegetation removal should be restricted to mud and flare pits wherever possible. Where grading or excavation is essential, salvage of the topsoil and stockpiling should be carefully considered.

3. Fluid formulations used at the wellsite should be those which lessen the impact on vegetation and soil, and increase the success of reclamation techniques. Undisturbed areas of native grasslands should not be disturbed to accommodate drilling waste disposal. Where remote sumps or on-site tankage is required, as in multiple well programs, measures should be taken to reduce the surface area affected. Drilling waste sumps should be designed to contain all fluids with no leakage.

4. Initiate cleanup and reclamation immediately following rig removal from the wellsite unless the soil is frozen or wet. Topsoil should be replaced, left with a rough surface and erosion control measures put in place. Revegetation should proceed as soon as practical following the disturbance.

5. Guidelines for surface disturbances relating to petroleum activity on the native prairie should be consulted in the early stages of wellsite planning.

5.3.2 Plant Sites

The implications of plant site development within native grasslands are similar to those outlined previously for wellsites. However, plant sites generally encompass larger areas of land and are more permanent or longer-term facilities. A development plan which considers plant and wellsite locations, routing requirements for pipelines and access roads is essential to minimize disturbances to the native grassland. Such facilities should be located in the least sensitive area possible.

The following recommendations to minimize the disturbance of plant sites in native grasslands are provided by the guidelines for surface disturbances by petroleum activity in native grasslands document (Special Areas Board et al. 1992):

1. Wherever possible permanent facilities should be located near all-weather main roads to avoid

unnecessary road construction through native grassland areas;

2. Existing trails should be used wherever possible and geotextiles and temporary road bases should be considered if access is required on sensitive terrain;
3. Soil sterilants should not be used for vegetation control at plant sites or any other sites within native grassland areas but rather, selective herbicides may be applied where weeds present a nuisance.

5.3.3 Pipelines

The distribution of oil and gas pipelines operated by Nova Corporation of Alberta and its subsidiaries within the grassland ecoregions of Alberta is illustrated in Figure 12. While additional pipelines occur throughout these ecoregions, Figure 12 is presented by way of an example of the geographic distribution of pipelines as owned and operated by a major pipeline company within Alberta. Table 10 summarizes the relative length of pipeline by ecoregion. A proportionately larger extent of pipelines occurs within the dry mixed grass ecoregion.

Installation of a pipeline typically results in an initial disruption of the soil properties of an area as well as the native flora. In some cases local hydrological patterns are also affected. Many of the changes caused by this disruption persist with time (Adams 1993; Naeth 1986; Naeth et al. 1987; Naeth et al. 1988). Pipeline route selection should be undertaken with a view to minimizing the extent of disturbance to native grasslands as well as avoiding highly sensitive areas wherever possible. This principle should be applied within all grassland ecoregions. Routes following existing access routes are often advantageous. Routing through low-lying, sheltered areas are preferred when native grasslands must be crossed. However, care should be taken to ensure pipelines avoid saline seepage or frequently flooded areas.

Changes in soil hydrologic properties may occur when a native grassland ecosystem is disturbed by pipeline installation (Cannon and Landsburg 1990; Naeth et al. 1987; Zellmer et al. 1987). Degradation of the soil during stripping and replacing operations may leave the soil more prone to wind and water erosion. Berms from backfilled soil in the trench may disrupt natural surface drainage patterns resulting in ponding and erosion. Areas of soil may be compacted and the groundwater flow regimes altered. Accordingly, all unnecessary disturbance to the vegetation and soil surface should be avoided. Grading should be avoided except at tie-ins, bell holes or other sites where larger excavations are required. The topsoil should be salvaged, stored separately and replaced during reclamation of the rights-of-way (R-O-W). Compaction should be alleviated by aeration or other methods.

In a study near Princess, Alberta (dry mixed grass ecoregion), pipeline construction activities and subsequent operation of the pipeline were shown to have had a profound effect on the native grassland (Naeth 1986). No topsoil salvage

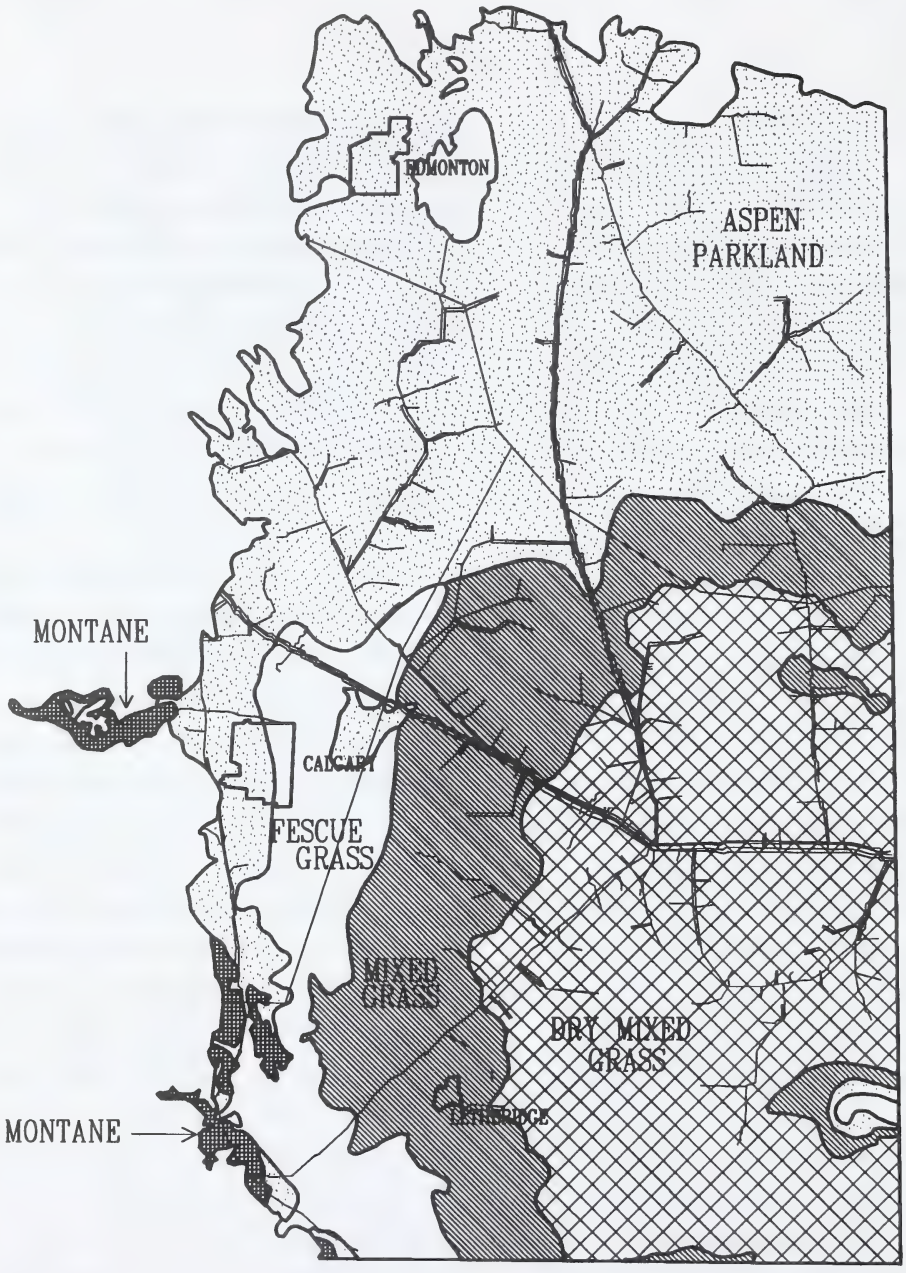


Figure 12. Distribution of Oil and Gas Pipelines Within the Grassland Ecoregions of Alberta (as Supplied by NOVA Corporation of Alberta)

Legend

— Existing oil and gas pipelines

Scale = 1:3 000 000

Source: Nova Corporation of Alberta, 1991

Table 10. Extent of Oil and Gas Pipelines Within the Grassland Ecoregions of Alberta.

Ecoregion	Length (km)
Dry Mixed Grass	2634.70
Mixed Grass	1468.26
Fescue Grass	563.14
Aspen Parkland	4020.62
Montane	130.66

Source: Nova Corporation of Alberta 1991

was undertaken, due to the small amount present. Trenching was done with a ditcher and then backfilled. Lands were graded as necessary. The most visible effects were the reduction or removal of vegetative cover on the R-O-W. Other effects included the construction of a berm which disrupted surface spring runoff and levelling of the land surface to fill in blowouts. Effects on the edaphic environment were less visible although some were longer lasting. The most extensive disruptions resulted from the trenching operation: vegetative cover was removed, clay content and near surface bulk density increased, and bulk density with depth decreased. Total soil water in the trench increased and water retention became more uniform with depth. However, plant-available water was not significantly affected. Soil surface temperature decreased in winter and increased in summer. Total soluble salts increased in the trench, particularly near the surface. Surface organic carbon decreased but there was no significant effect on pH. Grading and compaction by heavy equipment were less destructive than the trenching operation. Changes in bulk density with depth due to pipeline construction persisted with time but surface bulk density declined within 10 years (Naeth 1986).

In further evaluation of the area Naeth et al. (1987) found that problems associated with pipeline installation were linked to soil compaction, loss of, or mixture of, topsoil with subsoil, decreased organic matter content, disturbed internal drainage, increased surface stoniness and increased weediness. Disturbance significantly increased surface bulk density of soil profiles and soil organic matter was significantly lowered. This study concluded that the time needed to restore half the lost organic matter is approximately 50 years in the semi-arid to arid dry mixed grass ecoregion. Further discussion on the factors influencing the degree of disturbance and reclamation success is provided in Section 6.0.

Pipeline construction involves the removal of the existing vegetation on the R-O-W which can alter the physical and chemical characteristics of excavated and replaced soil materials. Water erosion on steeply sloped pipeline rights-of-way during the time between construction and

revegetation can result in severe soil loss, increased difficulty in reclamation and increased cost of reclamation and maintenance. The traditional means of stabilizing soil and inhibiting soil erosion has been the establishment of a rapid and dense vegetative cover. Indeed the objective of revegetation has until recently been largely viewed as a means to control erosion rather than to restore predisturbed vegetation conditions. For example, "The Resource Handbook, Operational Guidelines for Industry" (Alberta Energy and Natural Resources 1984) states that:

> "The prime purpose of revegetation, particularly seeding to grass, is to establish a root system as dense as possible as a defence against erosion."

While clearly erosion must be controlled, particularly on steep, erosive-prone sites, the use of rapidly establishing, dense cover-forming grass species may severely restrict the potential for native grassland species establishment. Where restoration of native grasslands is an ultimate objective of the reclamation program, more sophisticated approaches to revegetation may be required such as the combined use of physical control structures, tackifiers, cover crops and periodic maintenance seeding using native grass and shrub species to promote the gradual restoration process. This approach may require a longer time frame and additional costs; however, such costs may be necessary as reclamation standards become more stringent.

Under most circumstances, pipeline rights-of-way can be successfully revegetated using appropriate reclamation practices. However, during the period between disturbance of the R-O-W and re-establishment of an adequate vegetation cover, soil erosion can be locally severe and difficult to control, resulting in the loss of valuable topsoil. This is particularly challenging to reclamation efforts in semi-arid to arid ecoregions where topsoil depths may be restricted or where the topsoil is not particularly fertile.

The period of time required to reestablish the vegetative cover depends on the local environmental characteristics of microclimate, soils, vegetation and terrain, in addition to the general nature of the ecoregion. Mulches of straw, tackifiers or other materials are commonly used to aid in soil stabilization prior to revegetation (Zellmer et al. 1987).

5.3.4 Seismic

The environmental damage that improperly conducted seismic exploration can cause in sensitive native grassland areas often necessitates the use of specific protection and reclamation measures. Native grassland areas, especially when associated with steep or sandy terrain, may have easily disturbed surfaces, be susceptible to erosion and may be difficult to revegetate. This is particularly true of native grasslands within the semi-arid and arid dry mixed grass and mixed grass ecoregions.

The effects of seismic operations on the biophysical environment may be related to surface contouring, vegetation removal, excessive traffic, stream crossing, and fire hazards. A number of measures should be implemented for seismic

operations in native grassland areas to minimize the disturbances and the need for time consuming and costly reclamation (Saskatchewan Environment 1987a):

1. Planning of the seismic operation should be undertaken such that highly sensitive areas are avoided and the entire operation will affect the smallest possible area. Existing roads, trails and stream crossings should be used for access wherever possible. Where feasible, seismic lines should follow natural, low-relief contours and avoid streams, hill crests, side slopes and steep slopes, and areas of trees and shrubs.
2. Minimize unnecessary ground surface disturbance and vegetation removal. Avoid levelling of surfaces and, where snow removal equipment is used, raise the blades to protect the ground surface and low-growing vegetation from scalping.
3. Minimize vehicular traffic in the area and restrict vehicles and equipment to designated areas, utilizing existing roads or trails wherever possible. Heavy machinery should be equipped with low-pressure tires in particularly sensitive areas where regular tires could damage the ground surface or vegetation. Light-weight, portable drilling equipment and/or hand cut lines should be used for areas with highly sensitive terrain.
4. Halt operations when rain, melting snow or soft terrain would result in rutting. Wherever possible seismic work should be done in the winter.
5. Locate shot holes in the least environmentally sensitive areas. Minimize ground disturbance around the shot holes; excess cuttings and debris from shot holes should be replaced, spread thinly around the hole or removed.
6. Stream crossings should use existing or temporary bridges and the number of crossings of a waterway should be minimized. Care should be taken to ensure that brush, soil or other debris is not placed into the stream bed.

Any disturbance of native grasslands should be reclaimed, particularly in the semi-arid and arid portions of the mixed grass and dry mixed grass ecoregions. Reclamation requirements may be reduced considerably by careful field practices which minimize disturbance. There should be little or no need for reclamation following a well-conducted seismic program. Any necessary reclamation should be initiated as soon as possible following the disturbance to minimize the potential for erosion.

5.3.5 Mines

Land disturbances typically associated with mining in native grassland areas are related primarily to surface or strip mining. Generally, this process involves the removal of the vegetation, topsoil, and subsoil resources prior to stripping of the overburden, followed by resource extraction.

In assessing the potential disturbance of mining to native grasslands the areal extent of the mine operation, the intensity of the disturbance, and the duration of the disturbance must be considered. The areal extent of the disturbance is defined as that area of land which is physically affected by the mining operation. The intensity of disturbance can be examined through a comparison of the condition of the environment both before and after the mining operation. This is particularly important with respect to erosion processes where the relationship of plant and soil factors to runoff and erosion is important both during the mining operation and subsequently, during reclamation efforts. The duration of the disturbance is related to the protection of environmental resources, mainly salvaged soil resources, and the viability of the native species propagules contained in the soil. There is considerable importance associated with the salvage and protection of the soil resource, and subsequently, the reclamation of the soil such that it provides a suitable growth medium for vegetation. The intensity and the duration of the mining operation are the most critical factors affecting reclamation of native grasslands disturbed by this type of development.

Drainage system disturbance is an additional concern when surface mining operations are undertaken. Typically, during construction these operations will significantly alter the natural drainage patterns for the affected area as well as for adjacent areas. The goal of reclamation is to recontour the landscape to facilitate drainage during the mining operation and subsequently to reclaim the land, including drainage patterns, to as near a pre-disturbance condition as possible.

The results of studies in the shrub-steppe and grassland areas of the Northern Great Plains indicate that restoration of lands to a pre-mining condition requires extremely long periods of time in semi-arid ecoregions (McGinnies and Nicholas 1980; Parmenter et al. 1985). For example, after 7 years the strip-mined lands studied in Wyoming exhibited little similarity to the control area in terms of plant species and relative abundances (Parmenter et al. 1985).

Reclamation programs for strip mines in native prairie areas typically strive to stabilize the disturbed site, control weedy species and encourage establishment of beneficial perennial plant species. Rapid establishment of perennial plant species on disturbed sites will normally remedy potential problems of site stabilization and competition by weedy species. In some cases, a nurse crop of annual small grain species can provide the plant cover necessary to prevent erosion and runoff and later provide a stubble-mulch in which to seed perennial grasses, forbs and shrubs (McGinnies and Nicholas 1980). Site-specific edaphic conditions will dictate the methods by which the desired plant cover can most successfully be estab-

lished. One of the most important management practices for establishing any type of vegetation on mine spoils is replacement of the topsoil in order to enhance infiltration, organic matter content, structure, friability and soil fertility.

Current reclamation methods for strip mined lands typically consist of re-contouring the spoil, replacement of subsoil, re-spreading available topsoil, the addition of fertilizers, and seeding with a prescribed forage or native seed mix. Normal reclamation procedures in the Northern Great Plains are directed to the re-establishment of the native vegetation. Studies indicate that species diversity peaks in the first year of revegetation, followed by a gradual decrease and stabilization due to the increasing dominance of a few grass species over time (Parmenter et al. 1985; Redente et al. 1984). However, diversity values of seeded stands did not approach the diversity value of surrounding undisturbed vegetation. To increase stand diversity it is necessary to limit the proportion of aggressive colonized grass seed used in the revegetation mixture. The use of forbs and shrubs may also be appropriate for increasing diversity in areas of suitable microtopography. Additionally, research indicates the key to increasing plant diversity may be linked to increasing environmental heterogeneity, such as variations in soil depth (Redente et al. 1984).

Ancillary mine disturbances, such as haul roads, pose unique revegetation problems. Although the soil profile may not be drastically altered, as is the case within the mined area, these sites are generally highly compacted, which impedes root penetration and water infiltration, and promotes runoff. Because of such edaphic differences, revegetation success and species composition can vary between reseeded ancillary areas and the mined sites. Generally these areas need to be prepared for seeding by tillage using ripper blades (Redente et al. 1984).

6. FACTORS WHICH INFLUENCE THE DEGREE OF DISTURBANCE AND RECLAMATION

A variety of biophysical and cultural factors must be considered in the formulation of successful reclamation plans. In the case of native grasslands, the local climatic conditions, the nature of the terrain, (including slope angle and exposure); the physical and chemical properties of the soil; and the dominant plant species present in the pre-disturbed landscape must all be examined, in a holistic manner to determine the site potential for reclamation. Where restoration of native grasslands is an objective of the reclamation plan, considerable knowledge gaps exist in the literature on even the most fundamental of native vegetation topics including, for example, native vegetation community dynamics, species selection, the response of native species to regeneration and maintenance techniques, as well as the synergistic effects of native and non-native species interaction over time. Such data deficiencies greatly limit the current application of native grassland restoration efforts within Alberta.

An examination of the key biophysical factors influencing the degree of prairie grassland disturbance and reclamation is presented in the following section as background to the subsequent discussion of specific reclamation and restoration case studies. The information presented is intended to summarize the current status of knowledge on native grassland reclamation and restoration in these areas while identifying data gaps where they occur.

6.1 WEATHER/CLIMATE

Climate and weather have both long- and short-term influences on the biotic and abiotic processes involved in native grassland reclamation. Weather factors such as temperature, precipitation, insolation and wind have a strong influence on the initiation and rate of biotic processes, while climate may influence the long term nature of vegetation and soil development. The grassland ecoregions of Alberta are characterized by several climatic constraints which affect the ability to reclaim disturbed lands. These have been previously described (Section 4).

6.2 TOPOGRAPHY

Topography and its interaction with both macro and micro climatic processes results in a variety of surface conditions which must be considered in the formulation of revegetation plans. Topographic conditions, such as steep slopes and open, exposed plains, for example, often promote erosion and hinder the reclamation process.

6.2.1 Macrotopography

Ecoregions supporting native grasslands are characterized by a variety of macrotopographic conditions, as previously described in Section 4.

The macrotopography of an area typically influences the local climate and it is this relationship which is most important in reclamation efforts within native grasslands. For example, native grasslands occurring within the montane ecoregion and in the southern portions of the fescue grass, mixed grass and dry mixed grass

ecoregions are generally subject to windy conditions, the result of their location relative to the Rocky Mountains and the predominance of Chinook winds. Reclamation efforts in areas affected by strong winds typically require specific soil protection measures, such as the use of mulches and soil tackifiers or slat fencing, to prevent wind erosion across exposed plains or hill crest areas (Kerr and Morrison 1991; Saskatchewan Environment 1987b).

Native grasslands in the dry mixed grass and mixed grass ecoregions are subject to intense daytime heating and subsequent afternoon thunderstorms during the summer months. Intense summer storms have a high potential to cause water erosion on steep, erosive slopes when excess runoff is unable to penetrate the soil surface. Accordingly, specific protection measures, such as the use of berms, cross-ditches and soil tackifiers, may be required to ensure successful reclamation of native grasslands in these areas (Saskatchewan Environment 1987b).

6.2.2 Microtopography

The microtopographic features of a landscape largely determine the spatial distribution of plant communities as they are influenced by such parameters as slope aspect, slope angle, soil properties and drainage characteristics. The position of a soil profile on a slope, for instance, affects characteristics such as soil moisture and depth, while slope steepness affects the rate of surface runoff and erosion potential. Similarly, lowlying areas and lower slope positions are likely to be areas of accumulation for runoff and may also be affected by groundwater discharge or other conditions created by the presence of a high water table. Accordingly, a variety of protection and reclamation procedures may be necessary to suit specific microtopographic conditions within a native grassland area.

Within the microtopographic continuum, vegetation communities vary in response to microclimatic and soil conditions. The most notable variations in vegetation patterns often occur between north- and south-facing slopes, upper and lower slopes, and slope crests and depressions. For example, north-facing slopes, lower slopes and depressions are generally characterized by a more moist microclimate and deeper soil profiles. Erosion is typically less severe than for south-facing slopes due to less variability in climate, a more lush vegetation cover and a higher proportion of organic matter in the topsoil. Alternatively, south-facing slopes, upper slopes and slope crests are subject to intense evapotranspiration and temperature fluctuations resulting in drier soil profiles, a more sparse vegetation cover and a correspondingly higher risk of erosion. Where microtopographic diversity is great within an area to be reclaimed a variety of native species mixes may be required in response to a range of site-specific topographic, soil and microclimatic conditions.

6.3 SOILS

The size and intensity of disturbance plays an important role in the dynamics of reclamation. In general, the larger the area of the disturbance the less influence the surrounding

land system may have on natural reclamation through the provision of soil micro-organisms and plant propagules. Extensive disturbances can result in soil conditions which do not provide a base for natural revegetation processes and therefore require soil and vegetation amendments (DePuit and Redente 1988). However, smaller disturbances can often, over time, reclaim themselves if not affected by erosion, invasion by weedy species, or adverse climatic conditions.

Management of the soil resource is fundamental in the design of any reclamation program. Maintenance of soil fertility requires a balanced supply of nutrients and organic matter in the surface soil horizons to provide a base for vegetative growth. In addition to directly promoting vegetation growth, these factors also promote soil structure and consistency which is conducive to water penetration and rapid plant establishment and growth. The major soil factors determining the potential for reclamation are physical, chemical and biological properties. Often moisture is the limiting factor in successful reclamation due to the semi-arid conditions associated with most native grassland areas in Alberta.

Soil development is dependent on the interaction of climate, topography, parent material and organisms/plants over time. Hence, it is important to consider these soil forming processes when developing reclamation programs for native grasslands. The basic principal for reclamation with respect to these factors is to ensure that the soil microclimate is not adversely modified by the disturbance and that the topography is restored, as closely as possible, to its pre-disturbance condition. Reclamation of the soil microclimate requires that the integrity of the microtopographic and soil characteristics be maintained or reestablished, and that revegetation with a suitable native grassland species mix be undertaken as soon as possible following a disturbance.

6.3.1 Soil Order

Soil orders, as defined by the Canadian System of Soil Classification (Agriculture Canada Expert Committee on Soil Survey 1987) are based on properties of the soil profile that reflect the nature of the soil environment and the effects of the dominant, soil-forming processes. The soils commonly associated with native grasslands in dry mixed grass, mixed grass, fescue grass, aspen parkland and montane ecoregions have been outlined previously (Section 4). The following text details the characteristics of the main grassland soil groups, relative to reclamation objectives. However, the descriptions provided are of a general nature and are not intended to address all possible soil conditions.

6.3.1.1 Chernozemic Soils

Brown Chernozem

The extent of the dry mixed grass ecoregion corresponds largely to the brown soil zone in Alberta. Within this zone, Brown Chernozemic soils occur under sub- to semi-arid climatic conditions. Considerable stress may be placed on plants due to low moisture levels and soil conditions, such as relatively low levels of organic matter and associated low soil fertility levels.

Brown Chernozemic soils are typically developed on glacial till parent materials, with textures varying from sandy loam to clay. Generally profiles are well drained and prone to droughty conditions. The Orthic Brown Chernozem subgroup is characterized by the principle features of Brown Chernozemic soils. In native grasslands the topsoil often has a relatively low organic matter content, due to the type of vegetation cover and the decomposition conditions present. Soil structure and consistency are generally conducive to reclamation, except in areas where near-surface hard-pan or saline conditions are present. Prior to disturbance, the vegetated soil surface is relatively resistant to erosion by wind and water. Subsequently, however, erosion may be prevalent, particularly of topsoil which overlies compacted subsoil horizons or hard-pan conditions.

The subsoil (B) horizons are variable, depending on soil texture and parent materials. Generally coarse prismatic peds are associated with coarser-textured, sandy soils while finer-textured, clay-rich soils are characterized by blocky and granular aggregates. Calcareous Brown Chernozem and Solonetzic Brown Chernozem profiles are characterized by calcareous or solonetzic subsoil horizons, respectively. Specific care is required for the handling of these soils to ensure topsoil degradation does not result from the mixing of the topsoil and subsoil soil horizons. Furthermore, the subsoil horizons are more prone to compaction or salt movements as a result of disturbance.

The soil parent material is often calcareous, and not conducive to plant growth. Care is required during development and reclamation activities to ensure the parent material is not mixed with topsoil and, in some cases, subsoil materials. This is particularly true where Rego Brown Chernozems, characterized by the absence of a subsoil horizon, are present.

Dark Brown Chernozem

The mixed grass ecoregion corresponds generally to the dark brown soil zone in Alberta, although there is considerable variability of soil characteristics along the boundaries of the adjacent brown and black soil zones. The topsoil horizon of Dark Brown Chernozems is darker-coloured than Brown Chernozems, generally as a result of increased soil moisture and a higher organic matter content. The native vegetation is dominantly mesophytic, occurring within a semi-arid climate.

Orthic Dark Brown Chernozems are typical of native grasslands in the mixed grass, and other ecoregions. A gradient of soil conditions may be observed, with topsoil horizons becoming generally darker-coloured and higher in organic matter from southeast to northwest in the mixed grass ecoregion. The trend continues into the aspen parkland and fescue grass ecoregions where the soils grade into Black Chernozems.

Orthic Dark Brown soils are generally well drained, with loamy, organic-enriched topsoil horizons overlying brownish, prismatic or subangular blocky subsoil horizons. The rego, calcareous and solonetzic subgroups pose similar difficulties

to reclamation as previously described for the Brown Chernozem soils. Generally Dark Brown Chernozems have a moderate moisture holding capacity and there is less risk of droughty conditions than for brown soils of the dry mixed grass ecoregion. As a result of the increased soil moisture and higher organic matter content, the Dark Brown Chernozems are generally more receptive to reclamation efforts following disturbance of a native grassland area.

Black Chernozem

Black Chernozemic soils are typically associated with the fescue grass and aspen parkland ecoregions. The topsoil horizons of these soils are typically darker in colour and thicker than soils of the Brown and Dark Brown groups. Under subhumid climatic conditions Black Chernozemic soils usually occur in association with mesophytic grasses.

Generally Black Chernozemic soils are loamy to clay loam in texture, with deep, moderately well drained profiles. Orthic Black Chernozems are considered modal for this group, characterized by a black, friable topsoil horizon overlying a brownish-coloured, prismatic or subangular blocky subsoil (B horizon). Rego, calcareous and solonetzic subgroups occur in response to site-specific conditions and soil forming processes.

Black Chernozemic soil are characterized by a significantly higher soil moisture and more organic-enriched, fertile conditions than those soils of the dark brown and brown soil zones. Accordingly the black soils present fewer limitations to reclamation. However, in some areas limitations for plant growth and hence, revegetation, are generated by cool growing conditions and a shortened growing season. This factor may also affect the micro-biological component of the soil.

6.3.1.2 Solonetzic Soils. Solonetzic soils have characteristics which may adversely affect their productivity and resistance to disturbance, thereby resulting in special management and reclamation problems (Toogood and Cairns 1973). These are summarized in the following text.

Soils of the solonetzic order have solonetzic subsoil (Bn or Bnt) horizons which are very hard and compact, when dry; and which swell to a sticky, relatively impermeable mass when wet. As a result of the solonetzic B horizon, a hard-pan layer forms at the base of the topsoil layer, trapping rainfall near the soil surface and resulting in the loss of much soil water to evaporation. Plant roots, unable to penetrate the hard-pan layer, become concentrated near the soil surface where they cannot tolerate prolonged droughty conditions. This problem is intensified by the tendency for these soils to have relatively thinner topsoil (Ah) horizons than other associated soils. Erosion of the topsoil typically occurs above the hard-pan layer, particularly where surface disturbance has occurred.

Some solonetzic soils have a platy-structured, relatively infertile, eluvial (Ae) horizon which forms between the topsoil and the solonetzic subsoil horizons. Typically this horizon has

adverse affects on plant growth and, when exposed at the surface, may crust readily.

The chemical composition of solonetzic soils is often unfavourable for plant growth. The topsoil horizons are frequently characterized by low pH values which may adversely affect the availability of nutrients or other elements to plants. Solonetzic soils typically have low fertility levels and often require the addition of large amounts of nitrogen-rich fertilizers to promote plant growth. Because these soils have a high sodium content soil aggregates are often unstable, causing the soils to be highly erodible.

Subgroups of this soil order are designated on the basis of features indicating different climatic zones, as reflected in the colour of the A horizon, and degree of weathering. Solonetzic soils are typically found in association with chernozemic soils, within the brown, dark brown or black soil zones, respectively.

Solonetz

Solonetzic soils often occur in association with Brown, Dark Brown and Black Chernozemic soils, and are related to the presence of highly saline parent materials and low hydraulic conductivity. In association with Brown Chernozemic soils, Brown Solonetz soils are characterized by sub- to semi-arid climatic conditions, sparse xerophytic vegetation and patchy microtopography associated with erosional areas. The potential for reclamation in these areas is severely limited by climate, erosion, soil fertility and soil structure. Dark Brown Solonetz soils, occurring in association with Dark Brown Chernozems, are characterized by semi-arid climatic conditions and a native vegetation cover of mesophytic grasses. Bare erosional zones are less frequent in this soil zone under moister climatic conditions. Black Solonetzic soils occur in association with Black Chernozemic soils. The native vegetation cover ranges from mesophytic grasslands to discontinuous shrubs and trees and the micro-relief associated with differential topsoil erosion in the brown and dark brown soil zones rarely occurs.

The difficulty in reclaiming solonetz soils is related to the presence of a hard solonetzic B horizon, which is often prone to compaction and altered hydraulic regimes. The solonetzic B horizon may deter reclamation activities by presenting a barrier to root growth, reducing the water availability to plants, or promoting the erosion of valuable topsoil from above a relatively impermeable subsoil.

Solodized Solonetz

Solodized Solonetz soils are characterized by a near-surface zone of eluviation (Ae horizon), overlying a hard columnar or prismatic solonetzic subsoil (Bn/Bnt) horizon. There is a strong potential for erosion of the topsoil horizons overlying this hard, relatively impermeable subsoil. Root penetration of the subsoil is difficult for most plants resulting in problems for revegetation programs. The soils are often characterized by low levels of organic matter and soil fertility. As is the case for soils of the Solonetz order, profiles of the Solodized Solonetzic order may be subdivided as Brown Solodized Solonetz, Dark Brown Solodized Solonetz and Black Solodized Solonetz

on the basis of surface soil coloration, climatic conditions, soil moisture and organic matter content. The near surface horizons of these soils may be mottled as a result of soil water being trapped at the surface of the solonetzic B horizons. The lateral throughflow of soil water above the solonetzic B horizon may result in rapid erosion of topsoil resources.

Solod

Soil profiles which have undergone a significant degree of weathering, expressed by the disintegration of the upper portion of the solonetzic subsoil horizon, are classified as solods. The potential for vegetation growth is greatly improved over solonetz and solodized solonetz soils due to the increased ability for water to infiltrate the soil profile and for roots to penetrate to greater depths. As is the case for the previous solonetzic soil groups, profiles of the Solod soil group are subdivided as brown, dark brown and black according to soil climate, moisture and organic matter conditions.

6.3.1.3 Gleyed Soils. Gleyed soils are characterized by features which indicate periods of periodic or prolonged water saturation. They occur commonly in association with other soils in the landscape, either as gleyed subgroups or as gleysolic soil profiles which dominate depressions or areas associated with drainage channels or a high water table. Commonly the native vegetation occurring on gleyed soils is different from the surrounding, less moist native grasslands. Often the gleysolic soils have a deeper, more organic-rich topsoil horizon than soils of the surrounding landscape.

Gleyed soils present a number of specific problems for reclamation of native grasslands, including: compaction of peaty and mineral soils, poor soil drainage and difficulty in soil stripping. Generally, industrial development should avoid areas of gleyed soils. However, in some cases, soil profiles which are moderately to well drained at the time of development, and where the water table is sufficiently deep, may be handled in a manner comparable to the surrounding soils.

6.3.2 Soil Moisture

Water is an integral part of most soil processes, affecting soil properties and regulating plant growth and production. Hence, the capacity of a soil to store water generally determines its ability to maintain a viable vegetation community (Schroeder and Bauer 1984).

Water deficiency is the major factor that characterizes an arid or semi-arid ecoregion. Plants depend upon the entire continuum of soil, plant and atmospheric moisture to maintain an appropriate water balance. That continuum is heavily dependent on the water storage capacity and the release characteristics of the soil throughout the entire rooting profile. Those characteristics are affected not only by the soil's physical attributes and the distribution of plant roots, but also by the expansion of the water uptake zones by mycorrhizal fungi and by the organic matter component of the soil (Allen 1988). Accordingly, the maintenance and/or enhancement of soil moisture is of fundamental importance to the

success of revegetation and, ultimately, reclamation programs undertaken in native grasslands.

Minimizing soil disturbance, either by limiting the area of disturbance or by minimizing the number of times the soil is handled, reduces the potential for loss of soil moisture. Maintenance of soil organic matter, a component of the soil which aids in moisture retention, may be achieved by such practices as incorporating mulches or vegetation matter into the topsoil or by seeding topsoil piles during periods of prolonged storage.

Loamy soils have the best texture to promote a high water holding capacity, development of desirable soil structure and consistency, and resistance to erosion (Pitty 1979; Power et al. 1981). For the purposes of revegetation, the tasks of improving the water-retaining capacity of light, sandy or gravelly soils or, alternatively, making available to plants some of the moisture bound in heavy clay soils, are vital but difficult problems. Procedures, such as incorporating organic matter or fine-textured materials into sandy soils, or the incorporation of coarse-textured materials into clay-rich soils, are often successful in improving moisture availability to plants. However, when reclaiming native grasslands such dramatic modifications to the soil may not be practical, either because of the degree of tillage required for the incorporation process or due to changes which may result in the native vegetation community as a result of modified soil conditions. Generally mulches or minimally competitive cover crops are utilized to aid in retaining soil moisture while revegetation programs are underway in native grasslands (Fraser and Wolfe 1982; Schuman et al. 1985).

Permeability of the soil largely controls most aspects of soil wetting processes, and the soil water balance as a whole, including soil moisture and surface runoff. Permeability is dependent on a variety of soil conditions, including texture, structure, consistency, organic matter content, existing moisture, and mineralogy. It is also affected by the microbiological condition of the soil as well as the vegetation cover and nature of the associated root systems. Generally sandy soils have a high rate of permeability while clayey soils in semi-arid ecoregions tend to be at the opposite extreme.

6.3.3 Soil Physical Characteristics

Soil physical properties are an expression of the materials which make up the soil and of the climatic conditions, water and temperature, which affect them. As the processes which affect soil physical properties are largely interrelated, an effective reclamation program must strive to maintain the soil condition, in its entirety, or to reclaim the soil to the pre-disturbance condition. Readers should consult RRTAC report #91-4, "Soil Physical Properties in Reclamation" (Naeth et al. 1991b) for additional details beyond that provided by the following text.

6.3.3.1 Texture. Soil texture is an expression of the size distribution of the primary soil particles, referring to the relative proportions of fine, medium and coarse particles (clay, silt and sand) that make up the soil. It is, in part, the soil tex-

ture which governs such factors as the soil's ability to collect and retain moisture, the presence and exchange of soil nutrients with plants, and the potential for a soil to become compacted or eroded. Generally light soils (sandy) and heavy soils (clay-rich) are more difficult to reclaim than loamy soils due to the potential for erosion, compaction or moisture-retention problems. Sandy soils are characterized by a rapid infiltration rate and a low water holding capacity, often resulting in extremely droughty conditions for plants. They may be unstable when dry, and subject to wind erosion and rapid deterioration when disturbed. Conversely, clay soils may be difficult to work as they are prone to compaction, have a low water infiltration rate and bind soil moisture such that a portion is unavailable to plants. Often clay soils become sticky and slippery when wet and dry out slowly. They may also be subject to water erosion when present on moderate to steep slopes. Because of these characteristics, clay is generally the decisive fraction most influencing soil behaviour (Hillel 1980). Ideally, soil used for reclamation should not contain more than 30% to 35% clay and never more than 60% clay (Hargis and Redente 1984).

As part of development and reclamation planning, an analysis of soil texture is required for the baseline characterization of soils in all ecoregions of Alberta (Alberta Agriculture 1987). In order to adequately evaluate the suitability of the soil for reclamation it is necessary to characterize both the topsoil (A horizon) and the subsoil (B horizon). Tables 11 and 12 illustrate the guidelines commonly used to evaluate the suitability of soil texture for reclamation in the prairie regions of Alberta (Alberta Agriculture 1987). These guidelines are also generally applicable to native grassland reclamation in the montane ecoregion.

Soil stoniness has a significant effect on the potential for reclamation in native grasslands. Surface stoniness, including gravels, cobbles and stones occurring at the top of the soil profile; and, stone content, that volume of gravels, cobbles and stones occurring within the soil profile; may influence the ability of soils to be reclaimed by interfering with equipment operation. Excessive levels of surface or subsurface stones may also affect revegetation. Six stoniness classes are defined in the Canadian System of Soil Classification (Agriculture Canada Expert Committee on Soil Survey 1987), on the basis of percentage land covered by fragments larger than 15 cm in diameter. Stone content within soil profiles is expressed as a percent of the total soil volume for each horizon. The criteria for evaluating stoniness, relative to reclamation, are outlined in Tables 11 and 12. Where subsoil layers contain a significantly high stone content, special soil stripping practices, such as three-phase stripping, may be required (Alberta Environment 1991).

6.3.3.2 Structure and Consistency. The structure of the soil refers to the combination of primary soil particles into aggregates, classified on the basis of distinctness, size and type. Structure is not a stable property of the soil and it may vary with different soil moisture conditions. Consistency of the soil generally refers to its degree of

Table 11. Criteria for Evaluating Suitability of Topsoil for Reclamation in the Plains Region.

Rating/ Property	Good (G)	Fair (F)	Poor (P)	Unsuitable (U)
Reaction (pH)	6.5 to 7.5	5.5 to 6.4 & 7.6 to 8.4	4.5 to 5.4 & 8.5 to 9.0	<4.5 and >9.0
Salinity (EC) (dS/m)	<2	2 to 4	4 to 8	>8
Sodicity (SAR)[a]	<4	4 to 8	8 to 12	>12
Saturation (%)	30 to 60	20 to 30, 60 to 80	15 to 20, 80 to 120	<15 and >120
Stoniness Class[b]	S0, S1	S2	S3, S4	S5
Texture[c]	FSL, VFSL, L, SL, SiL	CL, SCL, SiCL	LS, SiC, C, S, HC	
Moist Consistency	very friable, friable	loose	firm, very firm	extremely firm
Organic Carbon (%)	>2	1 to 2	<1	
$CaCO_3$ Equivalent (%)	<2	2 to 20	20 to 70	>70

[a] Materials characterized by an SAR of 12 to 20 may be rated as poor if texture is sandy loam or coarser and saturation % is less than 100.

[b] S0 = non stony; S1 = slightly stony; S2 = moderately stony; S3 = very stony; S4 = exceedingly stony; S5 = excessively stony.

[c] S = sand; Si = silt; L = loam; C = clay; HC = heavy clay (F = fine; VF = very fine). Note: C and HC may be upgraded to fair or good in some arid areas.

Source: Alberta Agriculture 1987.

Table 12. Criteria for Evaluating Suitability of Subsoil Material for Reclamation in the Plains Region.

Rating/ Property	Good (G)	Fair (F)	Poor (P)	Unsuitable (U)
Reaction (pH)	6.5 to 7.5	5.5 to 6.4 & 7.6 to 8.4	4.5 to 5.4 & 8.6 to 9.0	<4.5 and >9.0
Salinity (EC) (dS/m)	<3	3 to 5	5 to 10	>10
Sodicity (SAR)[a]	<4	4 to 8	8 to 12	>12
Saturation (%)	30 to 60	20 to 30, 60 to 80	15 to 20, 80 to 120	<15 and >120
Stone Content (% Vol)	<3	3 to 25	25 to 50	>50
Texture[b]	FSL, VFSL, L, SiL, SL	CL, SCL, SiCL	S, LS, SiC, C, HC	Bedrock
Moist Consistency	very friable, friable	loose, firm	very firm	extremely firm

[a] Materials characterized by an SAR of 12 to 20 may be rated as poor if texture is sandy loam or coarser and saturation % is less than 100.

[b] S = sand; Si = silt; L = loam; C = clay; HC = heavy clay (F = fine; VF = very fine)

Source: Alberta Agriculture 1987.

cohesion and adhesion, and its ability to resist deformation. This largely determines a soil's erodibility and the potential for infiltration of air, water and plant roots. The structure and consistency of the soil are interrelated to a number of factors, including soil texture, chemistry, mineralogy and microbiological condition and, therefore, may be affected by modifications to any one of these factors.

Structure, in the form of aggregates at the soil surface, helps to ensure a stable system of soil porosity which is necessary to resist the disruptive effects of development on the soil. Most soil disturbance and reclamation activities reduce aggregate size, thereby increasing the potential for wind and water erosion. Remedial measures include chemical and organic amendments (such as manure), to promote re-development of aggregates and increase stability (Naeth et al. 1991). A stable soil structure aids in preventing erosion and promoting plant growth.

The criteria for evaluating soil consistency for reclamation are outlined in Tables 11 and 12. Consistency is important in determining the practical utilization of soils, such as for tillage, construction or compaction by machinery. Consistencies which present few to no limitations for reclamation are classified as friable, whereby the

soil particles have a significant degree of cohesion but are not so strongly bonded that they resist penetration of moisture or plant roots.

6.3.3.3 Bulk Density. Bulk density is a characteristic of the soil which describes the relative proportions of soil materials and voids in a soil. Its expression is strongly related to soil texture, and is also affected by organic matter and soil moisture. Typically soils with a coarse (sandy) texture are characterized by a high bulk density whereas finer soils (clay) have a lower bulk density (Pitty 1979). The relationship between organic matter and bulk density is inverse, with bulk density decreasing as the percentage of organic matter in the soil increases. The affect of soil moisture on bulk density varies depending on soil texture but generally bulk density decreases as soil moisture increases.

Changes in bulk density as a result of disturbance of native grassland soils are likely to affect permeability, drainage rate, trafficability, and penetration by plant roots and burrowing animals. Studies have shown that increased bulk density values on reclaimed grasslands resulted in significantly smaller total porosity values than for undisturbed grasslands (Schroeder 1987, 1989). Such physical changes influence the moisture content of the soil and plant environment. For example, a more compacted soil may be less capable of receiving and retaining soil moisture, and further, the revegetation process will often be hindered as plant roots must penetrate the compacted soil. This reduced ability of the soil to store moisture could particularly reduce the success of revegetation efforts in the Dry Mixed Grass Ecoregion.

6.3.3.4 Permeability and Infiltration. Permeability reflects the soils capacity to transmit water and is largely dependent on the size and shape of the pores and inter-connecting spaces in the soil. Infiltration represents the actual rate at which water is transmitted into the soil system. Soil permeability and infiltration rate are influenced by soil texture, structure, depth, and bulk density. Therefore, while clay soils may have a greater number of pore spaces than sandy soils, the individual pores are smaller and, as a result, infiltration rates are slower. The implications for reclamation efforts are related largely to the need to prevent a reduction of the soil permeability and infiltration rate. Soil compaction, for example, may have a significant negative impact on infiltration rates by reducing the size and/or number of pore spaces in the soil. This would, in turn, affect soil erodibility, soil moisture and the ability of the soil to support plant growth.

6.3.3.5 Soil Strength. Soil strength, while closely related to bulk density, is also affected by properties of cohesion, adhesion and shear strength.

Cohesion

Related to bulk density and soil moisture, cohesion is commonly measured as the soil's resistance to penetration, shearing or crushing. Even the loss of a small amount of soil moisture may cause a significant increase in the strength or cohesion of the soil. Strongly cohesive soils may

adversely affect the performance of tillage or seeding machinery, resulting in the need for additional working of the soil and the possibility that soils may become pulverized. Further, strongly cohesive soils may adversely affect the abilities of plants to extract moisture and nutrients.

Cohesion of the soil also affects the potential for soil erosion to occur, both during development and reclamation. Soil erodibility is directly associated with the physical strength of soil aggregates, and erosion by surface runoff or wind is typically greatest where cohesion between soil particles is low (Shiyatyy et al. 1972).

Adhesion

Adhesion is a force attributed to the molecular forces of water films which occur on soil particles. It is typically greatest in fine-textured soils with a high organic matter content. Adhesion is important to development and reclamation efforts in that it can affect the way in which machinery moves through the soil. Soils which become "sticky", for example are likely to hinder tillage or seeding processes and may prevent seeds from being properly placed in a seedbed. This may be a particular problem in solonetzic soils.

Shear Strength

Shear strength is a measure of the mechanical strength of the soil and determines at what point soil will become deformed when placed under stress. This is an important parameter for engineering uses of the soil but may be important for reclamation efforts as well. When soils are disturbed or recontoured their shear strength is affected to varying degrees. Some heavy clay soils, for example, loose much of their shear strength when disturbed, and are prone to landsliding (Chandler 1972).

6.3.3.6 Compaction. Soil compaction is typically caused by the movement of heavy equipment over the soil surface. As a result of compaction, soils experience an increase in bulk density at the expense of pore spaces vital to maintaining soil moisture. This process becomes increasingly important in the semi-arid or arid mixed grass and dry mixed grass ecoregions where limited soil moisture is available to vegetation under natural conditions. It is also a problem in clay-rich soils as compaction reduces the abundance of larger pore spaces in the soil, and the ability of plants to extract water is severely decreased. Subsequent to many types of development, compaction is a major limitation on soil productivity and, therefore, to revegetation (Cannon and Landsburg 1990; Schuler and Lowery 1986).

Compaction can be greatly reduced in native grassland areas by limiting the movement of traffic and machinery to designated areas. Subsequent to disturbance, compacted soils can be aerated to alleviate unnatural levels of compaction. To some extent, however, compaction is important for controlling erosion, and for promoting seed germination and plant growth. Reclamation efforts should ensure soils are not overworked in an effort to alleviate natural levels of compaction, and loose soils should be lightly compacted to a pre-disturbance condition.

6.3.4 Soil Chemical Characteristics

Soil chemical properties are an expression of the interaction between those materials which make up the soil and those materials which are added to the soil from the environment. Typically soil chemistry is dependent, not only on the nature of the soil properties, but also on the processes which are occurring within the soil environment. These processes are largely interrelated and effective reclamation programs must strive to maintain or reclaim the soil condition, in its entirety.

6.3.4.1 Chemical Processes

Redox Reactions

Oxidation-reduction processes, occurring in response to the presence (oxidation) or absence (reduction) of oxygen in the soil environment, have a significant effect on soil conditions. Microorganisms and active plant roots are usually involved in the oxidation process and depend on it for their survival. When oxygen is removed from the soil system, for example during water-logging, the oxidation states of elements and trace metals are modified resulting in the creation of distinctive soil properties, such as mottling or gleying. Soil fertility is also affected since the state of some nutrients and their mobility is dependent on this process. Accordingly soil disturbances in native grassland areas should avoid impacting wetland areas or drainage ways, and development should be limited to periods when the soil is not wet. Reclamation efforts should ensure the disturbed area is restored to its pre-disturbance condition and that areas of water ponding are not left in place.

Ion Exchange

The process of ion exchange in the soil is measured by the cation and anion exchange capacities. The cation exchange capacity (CEC) is considered to be the best single index of potential soil fertility in its capacity to exchange cations within the soil environment and between the soil and plants (Jackson 1964). Because the mobility of cations in the soil is related to other soil properties, such as clay composition, organic matter content and soil pH, the CEC of soils may vary greatly. In most native grassland areas the chernozemic soils have a relatively uniform organic matter content and the differentiating factor for CEC is often the mineral fraction of the soil, depending on the proportion of sands and clays in the soil. Where organic matter is lower, for instance in portions of the dry mixed grass ecoregion, it is likely the proportion of organic matter in the soil is a dominant factor controlling the CEC. Local conditions, such as the degree to which topsoil has been eroded, also have a significant effect on the CEC. Soils with shallow or eroded topsoil have a greatly reduced CEC and, therefore, have a decreased ability to support vegetation. Topsoil characterized by low CEC values may require fertilizer treatments to enhance soil fertility and increase the CEC during revegetation. However, the ability to enhance topsoil fertility by the use of fertilizers should not affect decisions on the protection and salvage of topsoil during reclamation.

Within non-saline soils the percentage of the cation exchange sites occupied by bases is referred to as the percent base saturation. In soils of the native grasslands in Alberta, calcium commonly accounts for a high proportion of the base saturation, a function of the abundance of calcareous rock in the soil parent materials (Brown et al. 1982). Magnesium, potassium and sodium typically make up the balance of the bases found in native grassland soils. Where sodium dominates the soil environment sodic soil conditions occur. Tables 11 and 12 outline the levels of saturation (%) which are considered suitable for soil reclamation in native grasslands and the levels of salinity and sodicity (EC and SAR) which hinder such activities. Saline and alkali soils are common in some semi-arid to arid grassland areas of Alberta, particularly where parent materials have a high salt content, where evaporation is high, and in depressional areas where regional or local groundwater recharges near to the surface (Sommerfeldt and MacKay 1982). Only a relatively few plant species are adapted to these areas and they are generally sensitive to disturbance, as are the soils themselves. The areas affected by these soils are often difficult to reclaim, once the groundwater regime, compactness of the soil, or the vegetation cover has been affected. Hence, these areas are best left undisturbed, wherever possible.

6.3.4.2 Chemical Conditions

Reaction (pH)

Reaction is the degree of acidity or alkalinity of a soil, usually expressed as a pH value. Soil pH is normally determined when the development and reclamation potential of soil is evaluated. Neutral pH values (6.5 to 7.5) typically provide the best soil conditions for plant growth and for reclamation (Tables 11 and 12). It is within a relatively neutral soil environment that micro-organisms are most active, soil nutrients are available to plants, and most harmful elements are bound within the soil and not available to plants or micro-organisms (Tate and Klein 1985).

Organic Matter

Organic matter is added to the soil by the presence of living matter, both plant and animal, at the surface and within the soil environment. It is a basic building agent in soil (Dormaar 1989). The maintenance of soil organic matter in native grassland ecosystems, particularly in semi-arid or arid ecoregions, is important because the organic matter provides and houses plant nutrients, enhances soil structure (granulation and aggregate stability), promotes infiltration and retention of soil water, enhances soil processes and microbial activity, and reduces wind and water erosion. There is a strong correlation between the erodibility of soil and the organic matter present. Higher amounts of organic matter serve to bind the fine soil particles making them less susceptible to erosion (Anderson and Coleman 1985). Additionally, organic matter provides vital nutrients for

vegetation and microorganisms which further stabilize the soil against erosion.

Plant, animal and microbial residues and root exudates and exfoliates are the major sources of carbon in soil. Plant root residues are the most significant source of organic matter, particularly in native grasslands. "Rhizodeposition" of organic matter, which ranges from 30% to 60% of the total root mass added, can provide energy-rich substrate to promote decomposition of more resistant humic (organic) components (Anderson and Coleman 1985). Accordingly, maintaining the vegetation root mat within the topsoil which is stripped prior to disturbances in native grasslands is important for the maintenance of organic matter in the stored soil and subsequently, when the soil is reclaimed. Soils which are stored for long periods of time, such as in areas where strip mining is occurring, would also benefit from the planting of grasses and legumes on the stockpile (Thurber et al. 1990). This process would not only aid in maintaining the organic matter component of the soil but would also provide a significant measure of erosion control.

Most organic matter in grassland soils is associated with finely-textured particles and aggregates. Accordingly, maximum concentrations of organic carbon occur in coarse clay or fine silty soils (Anderson and Coleman 1985; Arshad and Lowe 1966). Organic matter within the soil environment typically combines with metal cations and strongly influences the availability of micronutrients to plant roots and micro-organisms. As a source of nutrients, organic matter serves two main functions:

1. Since soil organic matter is derived mainly from plant residues it contains all the nutrients essential for plant growth. Accumulated organic matter, therefore, is a storehouse of plant nutrients and, upon decomposition these nutrients are released into the soil in a plant-available form.
2. The stable organic fraction of the soil (humus) adsorbs and holds nutrients in a plant-available form.

Hence, organic matter does not add any new plant nutrients but, rather, it releases nutrients in a plant-available form through the process of decomposition (Alberta Agriculture 1985).

The brown soils, characteristic of the dry mixed grass ecoregion, have the least amount of organic matter present in soil profiles because of the relatively small inputs of plant residues contributed by the dry mixed grass vegetation. Black soils, more typical of the aspen parkland and fescue grassland ecoregions, are characterized by a denser vegetation cover and a greater accumulation of organic matter. Organic matter present in native grassland soils (uncultivated) is estimated at 3% to 4% for brown soils, 4% to 5% for dark brown soils and 6% to 10% for black soils (Alberta Agriculture 1985). Reductions in organic matter following disturbance (including cultivation) of grassland soils are well documented (Anderson and Coleman 1985) although the implications of this process to soil productivity is diffi-

cult to quantify. Suggested minimum organic matter levels to maintain a stable soil system are 2.6% for brown soils, 3.3% for dark brown soils and 6.4% for black soils (McGill 1982).

The quality of the organic matter found in soil is often more important than the quantity because organic matter performs various fundamental functions in the soil. For example, a study by Dormaar (1989) at the Lethbridge Agricultural Research Station showed that the quality of organic matter in native grasslands was superior to that occurring in soils under cultivation. Under cultivated conditions the number of water-stable aggregates was reduced and there was a shift towards smaller particles which are more subject to wind erosion. Hence, although both soils tested contained the same quantity of organic matter, the quality had been reduced in the cultivated soil and it was more susceptible to erosion. Consequently, as a result of increased erosion the soil may lose organic matter, creating a cycle which continues to degrade the soil and leaves it less fertile and even more erodible.

Applications of organic materials to the soil generally improve productivity of reclaimed lands, particularly in areas of large-scale disturbance. However, because of the environmental conditions of some grassland areas, mainly the low levels of precipitation, organic materials applied during reclamation may be slow to decompose and integrate into the soil system. Accordingly, attempts to assess the potential of organic amendments to the soil during revegetation programs must consider the changes in soil chemical and physical properties as well as changes in the soil biological community (Fresquez et al. 1984).

Few studies have examined the progress of soil restoration following degradation or removal of organic matter or topsoil from an area. Studies by Dormaar et al. (1986) and Naeth et al. (1987) indicate restoration is slow and that after 22 years the soil of cropped lands located near the boundary of the dry mixed grass and mixed grass ecoregions had not fully recovered. Problem soils, such as associated with solonetzic rangelands in the dry mixed grass ecoregion, have been shown to have only half the lost organic matter restored 50 years following disturbance by pipeline installation (without amendments) (Naeth 1986). This process is expected to be considerably slower when active reclamation activities are not undertaken.

Studies indicate that it is easier to naturally reclaim soil to a state of undisturbed organic matter quality in the semi-arid regions of southeastern Alberta than to reach such a state of equilibrium in the more moist foothills regions. Recovery in the dry mixed grass and mixed grass ecoregions is estimated to require at least 75 years while 150 years is required in the more moist aspen parkland or fescue grass ecoregions (Dormaar 1989). This difference in recovery rate, while apparently contradictory from the perspective of climatic and vegetation conditions, is related to the types of grasses which dominate each ecoregion (Dormaar 1989). The rapid decomposition of blue grama grass in the dry mixed grass and mixed grass ecoregions, for example,

leads to a higher quality of organic matter, that may take only 75 years to reach equilibrium, as compared to the end product of rough fescue grass decomposition, in the fescue grass and aspen parkland ecoregions, which produces organic matter of a lesser quality.

Due to the long periods of time for natural restoration of organic matter to the soil environment, development planning and reclamation programs should focus on ways to preserve pre-disturbance reserves of soil organic matter or, alternatively, reclamation programs will require procedures which provide organic matter and associated amendments to the soil (e.g., mulches or fertilizers). Studies indicate a minimum of at least 1% organic matter should be present in reclaimed soils (Hargis and Redente 1984).

Nutrients

In most soils calcium, magnesium and potassium are distinct from other nutrients because they are originally derived from the primary soil minerals and they occur in significant quantities in exchangeable form (Barshad 1964; Buol 1965). Although concentrations of exchangeable potassium are often much less than calcium and magnesium, potassium is required and utilized by plants in much greater amounts. Unlike the other dominant soil cations, potassium is fixed by most soil clay minerals in a form not available to plants. Accordingly, this cation is often deficient in soils and may need to be added during reclamation of native grassland soils.

Nitrogen is added to the soil environment from the decomposition of living organisms and through the conversion of inert atmospheric nitrogen into various organic and inorganic forms by soil micro-organisms in a process termed "fixation". However, this process is often too slow for optimum plant growth and nitrogen deficiency is believed to be a major limiting factor in achieving productivity comparable to that of pre-mining plant communities (McGinnies and Nicholas 1980). Nitrogen deficiency on disturbed sites may result from insufficient or unsuitable topsoil, accelerated soil erosion, the disturbance of the vegetation cover and the activity of soil micro-organisms, the limited success of nitrogen-fixing micro-organisms, prolonged storage of the topsoil, and the mixing of subsoil with the topsoil (McGinnies and Nicholas 1980). Accordingly, fertilizer may be required to provide suitable levels of nitrogen for revegetation. Because plants typically recover less than half the nitrogen added as fertilizer, which is easily lost due to the mobility of nitrogen in the soil, a slow release fertilizer is recommended (DePuit and Coenenberg 1979).

Phosphorus is vital for plant growth (Pitty 1979). However, as there is no efficient mechanism for holding exchangeable and available phosphorus anions in the soil, and because phosphorus must be supplied to the soil almost entirely from the parent material, this nutrient must be added during reclamation. Multiple applications may be necessary as the fixation rate of phosphorus is high, when it is applied as fertilizer, and thus its recovery by plants is limited.

Salts

The total soluble salt content, or salinity, of the soil is frequently important because of the adverse osmotic effect that soluble salts have on the availability of soil water to plants. The proportion of exchangeable sodium in some soils may be high enough to seriously restrict water infiltration and movement, and consequently the potential for the soil to support plant growth (Power et al. 1979). Other salts, such as free calcium carbonate in soils, may affect soil aggregation, thereby also affecting water relations of the soil, and its erodibility.

The characteristics of sodium-based and other associated salts in soils are largely a function of climate or groundwater patterns rather than specific soil conditions (Doering 1982; Sommerfeldt and Oosterveld 1977). The accumulation of these salts in soil profiles is often related to hot, dry summers during which the concentration of soluble salts in soils increases as water is removed by evapotranspiration. If this process continues without subsequent leaching, excessive levels of salts eventually accumulate at or near the soil surface. Since the movement of these salts is based on water, the only means of control or reclamation is by water management (Brown et al. 1982; Rhoades 1982). Because disturbance of the soil surface often causes an increase in evaporation, once the vegetative cover is removed, care must be taken to avoid saline areas in native grasslands. Reclamation of salt affected areas frequently requires flushing of the salts away from the soil surface such that vegetation may be established. Alternatively, some areas are naturally more saline than others and there are a variety of native grasses which are suitable for revegetating saline soils, for example alkali grass (*Puccinellia nuttalliana*), salt grass (*Distichilis stricta*), western wheat grass (*Agropyron smithii*), and northern wheat grass (*Agropyron dasystachyum*) (Looman 1982). Soil salinity levels of $\leq$3 to 4 dS/m are considered tolerable for most plant species while levels exceeding 8 to 9 dS/m are considered unsuitable for all but the most salt-tolerant plants (Hargis and Redente 1984).

6.3.5 Soil Biological Characteristics

The biological characteristics of soil are a function of the vegetative and microbiological site conditions. In native grasslands one of the most important characteristics of topsoil is the presence of seeds and rhizomes of native plants (Powter, pers. comm. 1992). The effectiveness of these seed propagules in revegetating reclaimed areas is dependent on a number of factors, such as the time interval of topsoil storage, the method of stripping and re-spreading, and the species composition. Reclamation efforts on a pipeline R-O-W in the Morley Flats area of Alberta (Aspen Parkland - Montane ecoregion transitional zone) showed good success, immediately following construction, with revegetation from seeds salvaged in the topsoil resource (Morrison, pers. comm. 1992).

As a result of their diverse metabolic capabilities, soil microbes play both important positive and negative roles in reclamation. The

soil microbial community, whether or not it is intentionally managed, is indispensable for the successful reclamation of disturbed lands (Tate and Klein 1985). Soil micro-organisms contribute to soil structural development, synthesis of various plant nutrients through the mediation of different soil processes, and the amelioration of adverse chemical and physical limitations on the plant community. Micro-organisms provide an important service by decomposing soil organic matter and providing nutrients to the plant community. From a reclamation perspective, the amendment of reclaimed soils with organic materials may temporarily overcome the problems created by an inactive microbial community but the long-term stability of the soil-vegetation system depends upon the development of an indigenous microbial community (Tate 1985). Accordingly it is important that this parameter be evaluated when reclamation is required for severely disturbed developments, such as strip mining operations, which may dramatically disrupt the microbiological community.

In almost any disturbance some micro-organisms survive. Less severe disturbance results in greater micro-organism survival and the potential for more rapid and complete recovery of the soil processes important for revegetation and reclamation. The retention of topsoil resources, therefore, is critical to reclamation efforts as it is difficult to re-introduce suitable micro-organisms to the soil (Allen 1988).

A great concern following disturbance is the decrease in species richness of micro-organisms in the soil (Allen 1988). Of more concern is the loss of spatial structure of the micro-organism community. Several "technological fixes" have been proposed to aid in reconstruction efforts for disturbed lands (Tate and Klein 1985). These range from the use of new equipment for seeding or furrowing to genetically-engineered plants and micro-organisms with improved drought tolerance and greater plant productivity. For instance, salt-tolerant micro-organisms which are still capable of fixing nitrogen or transporting phosphorus to the host plant will be important to plant establishment in saline habitats. However, there are significant limits presently associated with these technologies, including a current lack of understanding regarding the survival mechanisms of organisms and their interaction with the surrounding environment.

For reclamation of native grassland areas in Alberta, the disturbed landscape requires immediate stabilization and the re-establishment of a permanent vegetative cover. In an effort to increase the rate of successful revegetation, such practices as the salvage or addition of organic-rich materials (topsoil, mulches) or heavy applications of fertilizers have been used for reclaiming disturbed sites (Allen 1988; Ringe and Graves 1987; Schuman et al. 1985). However, researchers have demonstrated that soil micro-organisms are potentially very important factors in aiding soil formation and revegetation through their activities as decomposers, nutrient cyclers and nitrogen "fixers". The importance of the soil microflora is paramount in ensuring satisfactory plant growth and subsequent formation of soil organic matter (Visser et al. 1983).

Soil fungi and micro-organisms generally require at least moderate moisture levels for growth (Harris 1971). Their capacity for decomposition processes may be appreciably reduced when moisture is low. Accordingly, the maintenance of soil moisture, particularly in the semi-arid ecoregions, is particularly important during reclamation efforts.

Soil micro-organisms in the rhizosphere are important in the revegetation and stabilization of disturbed areas in semi-arid ecoregions because the microbial community is often responsible for the modification of many adverse soil properties (Cundell 1977; Fresquez and Sabey 1989). These studies emphasize the importance of soil micro-organisms in ensuring satisfactory plant growth and subsequent formation of soil organic matter, the basis of a stable and well-balanced ecosystem. Generally these studies showed that in the first growing season after reclamation, the microflora composition consisted primarily of nonrhizosphere soil micro-organisms (Cundell 1977; Fresquez and Sabey 1989). Over subsequent years the dominant microbial community shifts to rhizosphere soil micro-organisms. The rhizosphere of native grasslands has been found to have abundant levels of soil nitrogen, phosphorus, organic matter and microbial populations. These changes in microbial populations and the types of micro-organisms present in the soil environment over time appear to affect nutrient cycling activities during ecosystem development or reclamation (Fresquez et al. 1988). The general conclusions of the studies by Fresquez and Sabey (1989) and Fresquez et al. (1988) is that the establishment of grasses on reclaimed topsoil for mined areas will essentially produce the healthiest soil and plant environment.

6.4 SITE AND SOIL MANAGEMENT

6.4.1 Preplanning

Reclamation of native grasslands is often difficult and should be assessed as a detailed component of all proposed development plans. Preliminary planning should include an overall inventory of the existing environmental conditions, as well as reclamation plans tailored to the specific development and the end land use (i.e., grazing land, wildlife habitat, natural parkland). Typically this preliminary planning is undertaken as part of a development and reclamation plan (D & R) or an environmental protection plan (EPP). The principle philosophy which should guide all preplanning activities is that avoiding environmental damage is preferable to and cheaper than reclamation, particularly in environmentally sensitive native grassland areas. The following items should be considered during the preplanning process:

1. Terrain - slope characterization, including aspect, angle and complexity;
2. Soil - topsoil and subsoil resource characterization (physical, chemical and biological)
3. Drainage Conditions - local and regional characteristics
4. Vegetation - inventory of the naturally occurring species and density;

5. Wildlife - knowledge of wildlife habitat and use of the area as well as use of the area by domestic livestock;
6. Land Use - the existing land use and proposed future land use;
7. Land Ownership.

A holistic approach should be used in preplanning, whereby all data are considered and evaluated together. Soil resources should be evaluated relative to the guidelines "Soil Quality Criteria Relative to Disturbance and Reclamation" as set out for prairie conditions in Alberta (Alberta Agriculture 1987). In critical areas, a land surface management plan may be required which identifies protection measures to be used in minimizing surface disturbance and reducing impacts on wildlife. This plan may address items such as vegetation diversity, conservation and reclamation procedures, assessment of wildlife habitat, procedures to be implemented to reduce overall disturbance to the surface, waste management, and landowner/lessee notification and concerns (Special Areas Board et al. 1992).

6.4.2 Minimal Disturbance

The concept of minimal disturbance is two-fold in that the smallest possible area should be disturbed by development and, within the development area the terrain, soil and vegetation should be subject to as little disturbance as possible.

Site planning should be undertaken to ensure any development within native grasslands makes use of lands with a maximum of efficiency and that lands should not be unnecessarily disturbed. Steps such as utilization of common rights-of-way (R's-O-W) for road access and flowlines, housing several wells on one pad site, and accessing sites off existing roads or trails, etc. should be standard to the planning process.

Within development areas, the land base will be disturbed by such activities as vehicular traffic and machinery movements; grading and topsoil stripping; excavating; etc. These activities should be undertaken in an efficient manner such that minimal disturbance occurs to the environment. The movement of vehicles or machinery should be limited to designated R's-O-W, preferably along existing roads or trails. Entry into and movement within native grassland areas should be limited to dry and/or frozen ground conditions only (Special Areas Board et al. 1992). No access should be allowed which results in uncontrolled rutting or breaking of the native prairie. Efforts must be made to avoid erosion wherever appropriate. Stripping operations should be conducted such that the soil resource is handled as few times as necessary to facilitate stripping and storage. In particularly sensitive areas soil stripping may not be advisable (Special Areas Board et al. 1992).

6.4.3 Site Preparation

A number of steps may be undertaken during the site preparation program to facilitate suitable reclamation and restoration of native grasslands.

Modification of the climatic, topographic and edaphic conditions of a disturbed site may be undertaken in order to influence the success of a

reclamation program. Most site modifications are, in principle, designed to accomplish one or both of the following: (1) creation of topographic and edaphic conditions conducive to the type of ecosystem ultimately desired; and, (2) provision of initial microclimatic, topographic and edaphic conditions favourable to establishment and growth of a plant community (Depuit and Redente 1988). With these goals in mind, specific site preparation practices may include the following:

1. grading/contouring to influence macrotopographic and microtopographic conditions;
2. mechanical treatment of the soil to provide protection, stabilization and erosion control; a suitable seed bed for revegetation; and, a healthy soil environment for the establishment and survival of the microbial community; and,
3. temporary augmentation of the climatic and/or soil conditions to relieve climatic constraints or soil fertility deficiencies, such as by irrigation or the addition of fertilizers (Depuit and Redente 1988).

Ultimately it is the goal of reclamation to recreate those site conditions present prior to disturbance of the area. Therefore, the predisturbance baseline terrain, soil and vegetation conditions should be adequately documented prior to development in native grassland areas.

6.4.3.1 Soil Conservation Efforts. Soil is the principle resource required for reclamation of any site. Typically this resource is divided into three distinct layers: the topsoil or surface layer (A horizons) which supports the majority of soil nutrients, organic matter and microbial activity, and which generally supports vegetation growth and contains viable seeds and rhizomes; the subsoil layer (B horizons) which is essentially an intergrade between the topsoil and the parent material, where most soil pedogenic processes occur and which has some capability for supporting vegetation growth; and, the parent material (C horizons) which often has little capability to supporting vegetation growth due to a lack of fertility and undesirable chemical, physical and microbiological characteristics. The combined depth of topsoil and subsoil (A and B horizons) typically provides the growth medium for plants. In some cases, where an upper subsoil horizon provides a significantly better plant growth medium than does a lower subsoil horizon, the subsoil may be handled in two lifts (Alberta Environment 1991).

An important part of the reclamation process is soil conservation and replacement involving the process of removing topsoil and subsoil from the land to be disturbed, then respreading it after the disturbance such that the land can be revegetated to its original or desired condition. However, disturbance of the soil resource, either through construction or stripping operations, may result in a number of negative impacts, including soil compaction, degradation and erosion.

Soil compaction is typically related to the movements of vehicles and machinery on the soil surface. The problem is decidedly more prevalent in soils with a high clay content (Cannon and Landsburg 1990). As previously discussed (Section 6.3), compacted soils are typically characterized by a reduced porosity and an increased bulk density, resulting in: a lower water infiltration rate and corresponding increase in surface runoff; a reduced ability for plant roots to penetrate the soil and to extract moisture from the soil; and, a decline in microbiological activity in the soil. Soil profile compaction on disturbed areas must be controlled to assist in revegetation (Special Areas Board et al. 1992).

Topsoil is a highly effective resource for maintaining or improving the chemical, physical and biological properties of reclaimed lands, thereby greatly enhancing primary productivity and the rate of revegetation. To maximize the value of topsoil as a resource it is necessary that no significant degradation of the chemical, physical and biological properties occur as a result of disturbing or stockpiling the soil. This topic is discussed in some detail in RRTAC report 90-5 (Thurber Consultants Ltd. et al. 1990).

The influence of topsoil replacement on the reconstruction of drastically altered lands cannot be over-emphasized. This one activity may do more for reclamation than any other procedure. The application of topsoil over disturbed parent materials or spoil induces secondary rather than primary succession, and therefore accelerates the recovery process (Howard and Samuel 1979; McGinnies 1980). The parent material or overburden materials are usually less suitable than topsoil and subsoil horizons for supporting vegetation, because they are low in organic matter and usually have a less favourable structure, aeration and infiltration capacity. Furthermore, these layers often lack available plant nutrients and micro-organisms which play an essential role in nutrient cycling, energy flow and soil structural development. In addition to providing micro-organisms, nutrients and a more favourable structural environment for plant growth, topsoil provides viable native plant propagules for added diversity in the plant community (DePuit and Redente 1988).

Protection from soil erosion, by wind and water, is an important consideration during and subsequent to development and reclamation activities in native grasslands. Studies indicate that soil loss from undisturbed native grasslands is considerably lower than for disturbed native grasslands, and that area of ground covered by vegetation and plant litter is closely related to soil loss by erosion (Ries and Hofmann 1984).

Studies in North Dakota indicate that the vegetation cover of native grasslands, which typically contains a high proportion of low, dense growing species, has a high proportion of live plants to litter at the soil surface. In comparison, reclaimed grassland areas often produce a cover with a high proportion of litter to live plants at the soil surface (Hofmann et al. 1983; Ries and Hofmann 1986). The studies further showed that soil protection in a native mixed grass community is largely obtained as a result of the live component of the total ground cover while protection

in a reclaimed mixed grass community results, to a greater degree, from the litter component of the total ground cover. Accordingly, careful monitoring and management of the litter component of total surface ground cover is needed to insure adequate protection from excessive soil loss by water erosion in reclaimed mixed grass communities (Ries and Hofmann 1986).

Rainfall, soil erodibility, length and steepness of slope, protective soil surface cover, and land use and erosion control practices are factors used in most models to predict erosion losses from soils. Measures of these factors and their relationships to each other from grassland and rangeland are limited. However, studies indicate that soils with a higher degree of disturbance do experience greater risk of erosion (Hofmann and Ries 1991), particularly if there is a delay between the time of disturbance and the establishment of a suitable vegetation cover. Accordingly, such practices as applying a mulch or soil tackifier, or installing berms, should be used to prevent erosion.

6.4.3.2 Site Contouring/Grading. Site contouring or grading of a disturbed area will be somewhat dependent on the extent of the disturbance, the environmental conditions and the desired end use. Typically small aerial disturbances should be contoured to a form consistent with the predisturbance and surrounding landscape. Areas of larger disturbance, such as where strip mining has occurred, should be landscaped to a condition which approximates the pre-disturbance condition but some modifications, such as reducing slopes, creating water bodies or other activities may be desirable for purposes of terrain stability, drainage control or creating specific end land uses.

Alberta guidelines for petroleum-related surface disturbances of native grasslands suggest that all disturbed sites should be contoured to their original soil profile and natural topographic condition (Special Areas Board et al. 1992). Care is required to ensure natural drainage patterns are not permanently blocked or changed by the contouring or grading process.

Contouring and grading activities associated with reclamation should be undertaken using the spoil or parent materials from the disturbance site. Regrading and contouring disturbed areas to their pre-disturbance condition is of prime importance in controlling erosion, as well as reclaiming disturbed areas to their original condition. Petroleum industry guidelines for backslope and fill slope angles are outlined in Table 13.

6.4.3.3 Soil Replacement. Numerous studies have shown the benefits of topsoiling for plant community establishment on western disturbed lands (Barth 1984; Hargis and Redente 1984; McGinnies and Nicholas 1980; Redente et al. 1982; Schuman et al. 1985). Subsoil and topsoil should be replaced over the reclamation area as the last step in site preparation. This process should receive the highest priority with respect to soil management as it is the zone which will provide the necessary growing medium for subsequent revegetation programs.

During reclamation the topsoil (A) and subsoil (B) horizons should be replaced and regraded with proper compaction and uniform

Table 13. Guide for Backslope and Fill Slope Angles for Different Soil Materials.

Backslopes	Horizontal:Vertical
Flat ground cuts under 1 m	2:1
For most soil types with ground slopes under 55%	1:1
For most soil types with ground slopes over 55%	3/4:1
Hardpan or soft rock	1/2:1
Solid rock	1/4:1
Fill Slopes	Horizontal:Vertical
Common for most soil types	1:1.5 to 0.5:1.5
Alluvial slopes	2:1
Ballast	1:1
Clay	4:1 to 1:1
Rock (crushed)	1.25:1
Gravel	1:1
Sand (moist)	1.5:1 to 1:1
Sand (saturated)	2:1
Shale	1.5:1

Source: Canadian Petroleum Association 1984

depth over the regraded and contoured area of disturbance. This process must be undertaken in such a manner that the quality and thickness of the rooting zone is comparable across the reclaimed site and is roughly equivalent to the average rooting zone occurring prior to disturbance. For successful restoration of a site to native grassland the soil material reclaimed will require sufficient depth and properties in order to store water to a field capacity suitable for the desired vegetation growth.

A study of reclamation using native grasses in the Northern Great Plains indicated that 40 cm of growth medium (A and B horizons together) will have an adequate field capacity to support revegetation of disturbed mine areas (Schuman et al. 1985). On the other hand, studies by Barth and Martin (1982) indicate that a plant growth medium depth of 50 cm is optimum for reclamation of neutral mine spoils in that area. Power et al. (1981, 1982) determined that the total plant growth medium need not exceed 90 cm (30 cm of topsoil) because water withdrawal and rooting depth for native grasses rarely exceeded that depth. Greater depths may be required over drastically disturbed sites, such as

strip-mined areas, to allow for uneven spreading, erosion and other factors such as sodic conditions (Power et al. 1979). On the other hand, the results of some studies indicate that successional changes of revegetated areas were most rapid on the lands reclaimed with the shallowest topsoil depths while those lands reclaimed with deeper topsoils were rapidly dominated by grasses. However, studies by DePuit and Redente (1988) provide evidence that different plant species will respond in different ways to topsoil thickness and, because of competitive interactions among species, the responses of various species will differ over time. Soil microbial activity can be variously linked to species composition, time and topsoil thickness. Such results are corroborated by other research in semi-arid disturbed lands, demonstrating varied responses of vegetation productivity, species composition and diversity to differences in depth and physicochemical attributes of topsoil. The use of topsoil as a site modification practice on disturbed lands has value in influencing plant community composition and below ground processes over the short-term (DePuit and Redente 1988).

The topsoil depths for soils occurring naturally in native grasslands varies between ecoregions and soil zones, as outlined in Section 6.3. Topsoil factors which enhance plant growth and production generally include organic matter, organic carbon, nitrogen, and other nutrients. This in turn, results in greater microbiological activity, enhanced soil structure and consistency and enhanced benefits of optimum water relations, aeration and resistance for root development. However, quantification of the relative importance of each factor and the interactions of all factors within the soil environment is not well documented.

While several studies have shown that above ground (excluding roots) grass production increases with increased topsoil thickness, little has been reported about the affects of topsoil thickness on rooting patterns. However, a study of reclamation in northwestern Colorado (McGinnies and Nicholas 1980) determined that three to four years are required before root systems (in weight and distribution) of plants reclaimed to drastically disturbed areas, such as strip mined lands, resemble those in natural soils. The study showed that root production improved in correlation with the thickness of reclaimed topsoil over spoil. This contributed significantly to the stabilization of the reclaimed area, enhancement of soil development processes, and increased the chances of plant survival during periods of drought (McGinnies and Nicholas 1980).

6.4.4 Surface Preparation

Surface preparation is a very important factor for the success of revegetation and reclamation programs, particularly in those environments which place a high degree of stress on vegetation seedlings.

Successful germination and establishment of seedlings requires a microsite which provides adequate soil water and temperature conditions, among other species-specific requirements. Evidence suggests that one of the most important

characteristics of a microsite that makes it a "safe-site" (a microsite with good conditions for germination) is its association with high humidity and soil moisture (Winkel et al. 1991). This is particularly important in arid or semi-arid native grassland areas where seeds sown deep or under litter have a higher success rate than those distributed at or near the soil surface (Schuman et al. 1987).

The ideal seedbed is one where the seed is surrounded by soil particles that are firmly packed around the seed to ensure conductivity of water from soil to seed. Seeds on the surface have varying amounts of contact with soil (Winkel et al. 1991). The microsites most suitable for germination may occur naturally as cracks and depressions in the soil surface, among surface gravels and among plant litter. They may also be created by modifications to the soil by seedbed equipment. Studies indicate germination is highest from gravel, followed by litter, cracks and finally bare soil conditions. Bare surface sites decreased in water content more quickly than did the other sites. Small-seeded species are thought to establish with minimal seedbed preparation, provided summer precipitation is adequate (Duebbert et al. 1981; Winkel et al. 1991).

The type of site preparation to be used is dependent on a number of factors, including the nature of the climate, terrain, soil and the species mixture to be planted. The tilled seedbed method has been traditionally preferred for seeding fine- to moderately-textured (clays and silts) soils. Coarse textured (sandy) soils may require alternative methods of surface preparation, such as planting the site to an annual crop for a year prior to seeding grasses directly into the clean, standing stubble. This protective-crop method of seedbed preparation can be applied on medium and coarse textured soils or steep slopes where wind and water erosion are problems. Duebbert et al. (1981) recommended delaying planting of the protective crop in spring until one or more crops of annual weeds have germinated and been killed by shallow tillage.

The seedbed should be firmly packed but not compacted, such as through the use of a spike-tooth harrow or corrugated roller after tillage. The tillage and compaction process should not occur when soils are wet.

Seeding should occur just prior to the high rainfall period to maximize soil moisture as seeds germinate. This will also promote adequate plant growth prior to the onset of late summer droughty conditions in many native grassland areas (Duebbert et al. 1981).

Control measures to reduce or eliminate undesirable vegetation and weeds should be planned during site preparation and implemented well in advance of grass seeding. Areas where weedy species are abundant may require some intensive management prior to and during seeding and reclamation to native grasses. It is essential to adequately control competing vegetation before attempting to establish native grasses. Inadequate weed suppression is the cause of grass seeding failures more than any other single factor (Duebbert et al. 1981).

6.4.5 Equipment

Equipment utilized for reclamation varies depending on the nature and extent of disturbance. Generally however, equipment is required for stripping and reclaiming topsoil and subsoil, grading and contouring as required, and seedbed preparation. In many instances bulldozers or backhoes are used for the movement of soil and for grading or contouring the landscape. Disc or harrow machinery is typically used to alleviate compaction and facilitate seedbed preparation.

The critical stage in reclamation of native grasslands is often the salvage and subsequent replacement of the topsoil layer. In pipeline operations involving the selective stripping of only the ditch line, the topsoil and subsoil (spoil) storage areas are on top of the existing sod layer with its vegetation intact. To prevent possible scalping of the underlying vegetation and to allow the native sod to be remain intact, NOVA Corporation of Alberta has recently developed a piece of equipment to replace the excavated spoil and topsoil material known as the "Prairie Protector" (Houser 1992). The equipment consists of a blade attached where the normal cutting edge would be on a grader. The "blade" consists of a series of progressively more flexible blades attached together. Operation of the flexible blade allows the stored topsoil material to be scraped back over the trenchline, conforming to changes in microtopography and significantly reducing scalping. Reclamation activities conducted on behalf of Canadian Western Natural Gas in the Morley Flats area of Alberta indicated that an experienced grader operator can effectively strip topsoil and avoid scalping the sod of native grassland environments (Morrison, pers. comm. 1992).

The primary requirements for planting perennial grasses and legumes include: (1) uniform distribution of seed at the proper rate per hectare, (2) placing the seed at the proper depth, and (3) firming the soil around the seed. Drills designed to plant a wide range of native grasses and legume seeds are commercially available. They are equipped with special seed boxes, agitators, depth bands, and packer wheels to meet the primary requirements of planting.

Ground vehicle and aerial broadcast seeding are not recommended unless terrain conditions preclude the use of drilling equipment. If broadcast seeding is required then the soil surface should be packed firmly with a corrugated roller or spike-tooth harrowing after seeding. Further information on seeding equipment is supplied in subsequent sections of this report.

6.4.6 Fertilizers

Ecological disturbances have frequently been noted to temporarily increase nutrient availability in soils (Redente and Cook 1986), which subsequently declines as nutrient cycling becomes more closed with successional advancement (Vitousek 1985). Despite this, initial deficiencies in plant-available soil nutrients still occur. Losses of mobile nutrients freed by topsoil disturbance may be increased by the loss of soil structure and nutrient-cycling biota or by topsoil storage prior to reapplication. Further, it is often difficult to salvage topsoil with absolutely no mixing of subsoil, thereby resulting in some dilution of nutri-

ents. Consequently the use of inorganic fertilizers may be required to correct nutrient deficiencies and improve plant establishment during reclamation (DePuit and Redente 1988). In general studies have indicated that:

1. little effect of fertilization is seen in reclaimed lands during the first year after fertilization but significant effects may be noted several years later, suggesting that the effects of fertilization sometimes require time for full ecological expression;
2. fertilization enhances the growth and competitive ability of aggressive perennial species but that over-fertilization typically contributes to stand deterioration;
3. under conditions of excessive fertilization the production of plant biomass exceeds the ability of some reclaimed soils to decompose it, resulting in massive litter accumulations at the soil surface, altered microclimatic conditions, immobilized nutrients, a disrupted nutrient cycle, and ultimately, reduced plant vigour over time; and,
4. the application of nitrogen and phosphorus fertilizer increases the initial total vegetation productivity but over time, with repeated fertilizer applications, community diversity is reduced, particularly at the expense of native grasses, forbs and shrubs which are less able to compete with invasive, non-native species (DePuit and Redente 1988).

In the native grassland areas of Alberta considerable attention should be given to the appropriateness of fertilization during reclamation programs. Many native species of semi-arid and arid ecoregions are adapted to conditions of relatively low soil fertility (DePuit and Redente 1988). This characteristic, coupled by the typically slow establishment rate of native grasses, would make semi-arid or arid areas seeded with native species theoretically less responsive to short-term fertilization or irrigation practices. Fertilizers should only be added where appropriate for the soil conditions and the needs of the revegetation program. It is important to note that improper fertilization practices are often as detrimental to vegetation as a lack of soil fertility. If fertilizers are not necessary they may also add an unnecessary cost to the reclamation program.

Another study by DePuit and Redente (1988) supports the theory that areas reclaimed with native grasses may not require fertilization. They found that fertilization often reduces species diversity in reclaimed areas because: (1) the application of nitrogen-rich fertilizer may reduce the nitrogen-fixing advantage held by legumes while increasing the growth rates of vigorous, nitrogen-responsive grasses, allowing the latter to rapidly dominate the community; and, (2) there is some evidence that fertilization favours earlier growing species at the expense of later growing

species. Furthermore, their findings indicated that fertilization may also retard development of certain components of the microbial community. Fertilization of range and reclaimed disturbed land was frequently found to stimulate growth of weedy or pioneer species. Not only were these species found to be undesirable, but they are often non-mycorrhizal and, as such, tend to retard mycorrhizal (microbial) colonization of reclaimed soils (DePuit and Redente 1988).

Conversely these findings, studies by Biondini et al. (1985) indicate that there is little to no direct, long-term correlation between fertilizer applications and the success of native seed mixtures for revegetation. Thus, in native grasslands, the effects of fertilizer become less distinct in the succeeding years after revegetation, suggesting subsequent fertilizer applications are needed.

6.4.7 Contaminants

The extent of contamination of native grasslands is not well documented. The data available for other landscapes, however, suggests that contamination of Alberta soils is generally site-specific in nature. Practices which may lead to severe or widespread contamination of soils or other components of the environment should, however, be avoided, especially in semi-arid native grasslands where a particularly fragile environmental balance is present.

The possible role of native grassland species and specialized cultivars in the reclamation of contaminant sites, while in its infancy, emphasizes the importance of maintaining native species diversity and a correspondingly wide gene pool.

6.4.7.1 Oils. Oil contaminated soils, either the result of spills or due to the landfarming of oily wastes, may be reclaimed using soil microorganisms as oil decomposing agents (Beak Consultants Ltd. 1981). However, the rate of application of oily waste to a particular soil; the potential for the microbial community to degrade oily waste, particularly in semi-arid areas; and, the potential for contaminants to be present in the oil; are issues which must be addressed to ensure oils do not contaminate native grasslands.

A number of techniques are being developed to facilitate the reclamation of petroleum hydrocarbons from soils. The main treatment technologies include thermal treatment, stabilization/solidification, soil washing, flotation techniques, solvent extraction, substitution and reduction-oxidation techniques, and biological treatment (Beck et al. 1991).

6.4.7.2 Metals. Metals in soil may originate from a number of sources, including soil parent material, fertilizers, or waste effluent or sludge material. Metals generally increase in solubility as soils become more acidic. The general concern regarding metals in the soil environment is their potential to become toxic to plants and soil organisms, and ultimately to higher organisms (animals and man). Research in Alberta suggests that the greatest proportion of metals present in soils originate from waste materials (Nason, pers. comm. 1990). Techniques to control or remediate metal problems are often element-specific and may require long periods of time.

6.4.7.3 Salts. Salts affect vegetation in two main ways. Initially they interfere with water relations of plants making it difficult for them to draw water from the soil. Secondly, specific ions within the salt influence plant metabolism and the uptake of essential ions from the soil. Salts dissolved in the soil solution originate from several sources, including parent materials, minerals in the soil itself, irrigation water, and spills from the petroleum industry. Considerable difficulty is encountered when growing vegetation in salt-affected areas, either on areas prone to natural saline seepage, where saline waste materials have been deposited, or where saline spills have occurred.

Research is ongoing to devise ways of overcoming the deleterious effects of salts on vegetation growth. Methods such as modifications to groundwater movements or percolation leaching of salts from soils do have some practical applications and may be considered on a site-specific basis when reclamation planning is underway. Studies on the reclamation of saline soils using drip irrigation and widely spaced deep furrows in planting indicates that spot irrigation with small amounts of water, sufficient to drive the majority of the salts beyond the plant root zone, speeds vegetative growth. Similarly, good vegetative growth of grasses in harsh saline environments has been achieved by planting seeds in 10 to 15 cm-deep furrows spaced at 30 to 55 cm intervals. This spacing reduces plant competition and permits concentration of the water into furrows while directing salts to the ridges between them (Dean et al. 1986).

Studies by Halvorson (1984) support the findings that, over time, the salts accumulated in seepage area will be washed (leached) from the soil surface to depth within the profile, thus allowing improved growing conditions for plants at the soil surface. Reclamation treatments to enhance this process can include soil ridging to reduce runoff and maximize leaching, straw mulching to reduce evaporation from the soil surface, the application of gypsum, and the planting of salt-tolerant species such as foxtail barley and kochia. Using active soil management practices that enhance water movement through the soil profiles and promote desired vegetation growth has generally been found more effective in reclaiming saline seepage areas than just letting the seepage area become revegetated naturally (Halvorson 1984). In some instances therefore, disturbance of a saline or solonetzic area, and successful reclamation, may actually improve the seepage area for native vegetation (Naeth 1986).

6.4.7.4 Pesticides. Pesticides are generally used to remove undesirable weeds, insects, fungi, nematodes and some rodent pests from an area. Concerns regarding the use of pesticides include carryover and the persistence and accumulation of pesticides to toxic levels in the soil; the effects of pesticides on non-targeted soil organisms and plants, resulting in disturbance of the balance of biological processes in the soil; and, the binding of pesticides to the soil and their subsequent release after a period of accumulation, resulting in toxic effects to soil organisms and plants (Campbell and Associates 1990). Persistence and carry over of

pesticides is greatest in dry years and on highly organic soils.

The use of pesticides when reclaiming native grasslands may be required to control weeds or other pests which are negatively affecting the potential for the disturbed area to be successfully restored to its pre-disturbance condition. Practices such as the use of non- or low-residual pesticides should be implemented during development, operation and reclamation of all sites. Alternatives such as mechanical or biological control of pests should be investigated prior to the use of pesticides. However, at present these methods are generally not well researched or developed.

The use of pesticides and their existence as soil contaminants is not well documented in Alberta. Where soils have been contaminated by pesticides the development of a rehabilitation program must consider the nature and concentration of the contaminant, the soil type and topography, water, the land use, and the availability of additives. The principle modes of reclamation and rehabilitation include adsorption (physical binding by charcoal) and biological degradation (Cotton and Sharma 1992). Excavation of the contaminated soil may be required in some instances.

6.4.7.5 Sewage Effluent and Sludge. Municipal and industrial sewage effluent is sometimes collected and treated for use in irrigation programs. Sewage effluent contains available plant nutrients with quantities of nitrogen approaching or exceeding that amount which is generally required by plants. The amounts of effluent irrigation water which may be applied to an area are controlled by the net moisture deficit, leaching requirement, the type of vegetation cover present, and the nature of the effluent (McGill 1982).

The difficulties in using sewage effluent for irrigation may include a high salt content in the water, the presence of higher level of nutrients than may be required by the vegetation and soil community, and the presence of trace metals. However, while research suggests that sewage effluent can be used effectively and safely for irrigation, the use of sewage sludge in reclamation programs for native grassland areas is not specifically documented. While it is feasible that this activity may enhance the potential for successful reclamation of a site, the characteristic of the site should be carefully evaluated and the landspreading program carefully planned to alleviate the potential for negative impacts. Reclamation planners should consult the Alberta Sewage Guidelines.

6.5 REVEGETATION

Revegetation has been defined as the "replacing of vegetation on a formerly vegetated site" (Trottier 1992); or, the "establishment of a vegetative cover not representative of an authentic plant community on a non-vegetated site" (Collicutt and Morgan 1991). Although revegetation is still a common reclamation goal, there has been increasing interest in recent years in restoration, or "the re-creation (or attempt at re-creation) of an authentic plant community on a site where that particular community no longer

exists" (Collicutt and Morgan 1991). Restoring rather than revegetating ecosystems may involve "providing habitat for the preservation of species and ecological phenomena, restoring sound ecological function to badly damaged landscapes, or re-establishing biological diversity" (Jenkins 1972).

Prairie restoration is therefore a complex and relatively recent discipline within the broader field of reclamation. It is still rather poorly understood when it comes to the application of techniques and methods which have as their objective the re-establishment of functioning prairie ecosystems. Simply making use of native grasses in revegetation projects is not prairie restoration as pointed out by a number of authors (Kindscher 1990; Pleznac 1983).

While the literature available on prairie restoration is expanding, particularly in the United States, much of the information pertaining to restoration projects is anecdotal or observational. In a recent review of native grassland restoration literature in general and tall grass prairie in particular, Collicutt and Morgan (1991) quote Mlot (1990) who refers to the body of information amassed by restorationists as the "folklore" of restoration techniques. They also point out that in their consideration there were no major empirical restoration projects which have been or are being carried out in an experimental fashion in Canada. The largest project that they were aware of was in Beaudry Provincial Heritage Park west of Winnipeg where Manitoba Parks Branch intends to restore 250 hectares of agricultural land within the park to native tall grass prairie. Nevertheless, research in this field has increased significantly within the last twenty years, fostered by a variety of private, government and nongovernment agencies. Within Alberta one of the Prairie Conservation Action Plan's objectives is to promote research relevant to prairie conservation. A specific goal is to identify a research centre which would "direct and encourage applied research on native prairie ecosystems" (Prairie Conservation Co-ordinating Committee 1991). Further, guidelines are being prepared to identify research topics and requirements in the areas of biotechnology, plant breeding, propagation and cultivation, soil science, crop science, animal science, reclamation and rehabilitation, and species recovery".

Much of the existing published literature on prairie restoration is documented in the proceedings of the biennially held North American Prairie Conferences, which originated in 1970. Collicutt and Morgan (1991) summarized the development of research topics and advances presented in these proceedings, while also pointing out data gaps which remain. Some examples cited include those of Stephenson (1970) who criticized the lack of attention to experimental design and research in previous restoration projects. Schwarzmeir (1973) used ecological theory to present concerns over ethical problems in restoration including translocation of local plant varieties, or ecotypes. Woehler and Martin (1983) presented a detailed study of vegetation change over six years in a prairie restoration project in southern Wisconsin relating the patterns of establishment and success of individual species while Harper (1983), presented criteria for evaluating

the success of prairie restorations. It was noted that she had identified the need for more objective and consistent assessments of such projects as restoration becomes a more common practice. Burton et al. (1988) tackled the issue of applying ecological theory to prairie restoration, discussing such topics as niche theory, spatial heterogeneity, landscape ecology and plant community structure. Collicutt and Morgan (1991) also comment on Burley's work (1989) which provides information on developing construction specifications for prairie landscaping. They concluded that such articles are indicative of an increased level of acceptance of restoration practices.

The following section summarizes the findings to date on a number of revegetation topics as they relate to native grassland reclamation and restoration. An analysis of the information is also provided to point out information gaps which exist particularly within the Alberta setting.

Regardless of whether reclamation will be comprised of revegetation or restoration, certain steps are fundamental in order to enhance the opportunities for success. These include:

1. The site should be inventoried to determine the composition and density of plant species which make up the existing vegetation community. If reclamation is to utilize native species, the inventory should identify species which could be used. This may allow the harvesting of seed or salvage of native plant materials on site prior to disturbance, for use in subsequent reclamation.
2. Successional trends should be noted, for example where shrubs and trees are encroaching on grassland areas. Successional processes will determine the rate and nature of initial revegetation and influence subsequent community development long after treatments have been implemented (Redente and DePuit 1988). Depending on regulatory requirements, the objectives of reclamation, site conditions, and type of disturbance, it may be possible to allow natural succession to reclaim the site.
3. Site environmental parameters, including topographic conditions, soil type, texture, moisture availability, exposure, and any additional site conditions which would influence reclamation should be evaluated. An understanding of the relationships between plants, animals, micro-organisms, soil and climate will assist in the re-establishment of stable, functional communities on disturbed lands (Allen 1988; El-Tayeb 1989; MacMahon 1987). Species should be selected which are adapted to site-specific conditions.

4. A monitoring program should be designed to assess the trends and the degree of success of reclamation efforts.

6.5.1 Species Selection

The selection of plant species is critical to the ultimate success of reclamation (Betz 1986; Collicutt and Morgan 1991; Rock 1981; Schramm 1976). Although the sophistication with which native plant species are chosen for use in native grassland reclamation projects is increasing, the knowledge base upon which decisions are made within a Canadian and local Alberta setting is still in an early stage of development, particularly where restoration objectives are concerned. A more thorough understanding of the complexity of native prairie community dynamics would assist in the formulation of site specific restoration techniques. For example, the importance of selecting locally adopted ecotypes which have developed in response to a specific elevation, microclimatic regime and local site conditions needs further research. Similarly, the basic floristic composition and structure of the seed mix and the variation in response to variable site conditions within different areas of the Canadian prairie ecoregions appears fundamental to successful species selection. Perhaps above all, the role of time in the evaluation of various restoration techniques requires a commitment to a long term monitoring of field plots and restoration trials.

In choosing plant species to reclaim a disturbed site the following factors should be taken into consideration:

1. The end land use of the site to be reclaimed must be clearly understood in order to establish the goals and objectives of the revegetation program. This will entail an assessment of the size of the area to be reclaimed, an understanding of local site conditions, a description of adjacent land uses and a cost estimate to complete the reclamation program.
2. The cost of reclamation using native species is usually higher compared to using conventional agronomic species (T. Andersen 1992, personal communication). This is primarily due to the shortage of seed supply combined with the difficulties of seed collection and cleaning.
3. Species, whether native or agronomic, should be adapted to the local climate and physical environment (Ries et al. 1987b; Schaller and Sutton 1978). Most authors that recommend species compositions for reclamation specify different arrays for xeric, mesic and wet conditions (Bowen 1990; Rock 1981). Grass species in particular exhibit a wide degree of ecological tolerance to flooding, drought, salinity, acidity, alkalinity, heat and cold.

4. If native species are to be used, an initial list of candidate native species should be compiled from a site inventory or a review of species lists from similar sites and discussion with native seed suppliers and/or local prairie restoration companies, where these exist. Ecoregions such as the dry mixed grass or tall grass prairie tend to have fairly unique and discernable species compositions (Collicutt and Morgan 1991). Species should be representative of the original community. In some cases, recommended species compositions for certain geographic regions are available (Hardy BBT 1989; Harper-Lore 1990; McLain 1986; Rock 1981; Schramm 1976).
5. The availability of native species may be limited. While sources are increasing each year, agronomic species are still more widely available.
6. A mixture of forbs, grasses and possibly shrubs rather than a monoculture of a few, highly competitive species will provide food and cover for a diversity of animal species. A diverse plant community generally also has more aesthetic appeal.
7. The use of species which are long-lived, competitive and/or invasive such as crested wheatgrass, smooth brome grass, timothy and red fescue should be avoided if native plant succession is desired (Walker 1989).
8. Competitive relationships, mutualism, and predator-prey relations in the community should be taken into account when compiling seed mixes (Call and Roundy 1991).
9. Overstory shrub plantings may increase the establishment of understorey species. For example, shrubs can catch windblown soil, seeds and mycorrhizal spores, and provide resting sites for animals to bring in seeds. The decreased irradiation and re-radiation resulting from shrub planting may affect understorey temperatures which may, in turn, decrease evapotranspiration and increase nutrient cycling. Shrubs may also decrease insect herbivory of associated plants by providing habitat for insect predators (West 1989). The presence of shrubs or trees has been shown to increase productivity compared to associated shrub-free grass stands

(Frost and McDougald 1989; Rumbaugh et al. 1982).

There are advantages and disadvantages to using both agronomic and native species in reclamation. While the relatively lower costs of agronomic versus native species may be seen as a cost saving advantage in reclamation this must be countered in terms of the disincentive which the cost differential creates in the use of native species. The advantages of selecting agronomic or introduced species can be summarized as follows:

1. Most are competitive, long-lived, produce prolific amounts of seed which are easily dispersed, can produce vegetatively, and have good ability to withstand grazing, mowing, burning, mechanical and chemical treatments (Romo and Lawrence 1990).
2. There is more accumulated knowledge at present on how to prepare seedbeds, seed and manage stands of introduced species compared to native species (Sims et al. 1984).
3. Until recently, there has been considerably more effort directed to the development of machinery and equipment to harvest and seed introduced species with a correspondingly wider selection of equipment to choose from.
4. Under certain site conditions, specific agronomic species outperform native species, particularly in the initial stages of revegetation (Sims et al. 1984). However, care is required not to use persistent or invasive agronomic species.

Caution should be expressed, however, in the comparison of native and agronomic species "success" in reclamation given the lack of data available within the Canadian prairie ecoregions. Sims et al. (1984) indicate that while a few studies have attempted to compare native to agronomic species subjectively, "statistically tested quantitative evaluations are virtually non-existent".

The main disadvantages of using agronomic species in a reclamation program lie in their competitive nature, which may prevent encroachment of native species and conversely, may also invade and out compete native species in adjacent areas. In some cases, they may do poorly if intensive maintenance, such as fertilization and irrigation ceases (Bell and Meidinger 1977).

The advantages of using native species include the following:

1. Once established, native species generally require less maintenance because they are well adapted to local conditions (providing appropriate species have been selected for the site). Native species in the drier ecoregions in particular are adapted to drought and soils of low fertility and therefore should not require costly irrigation and fertilization.

2. They may provide a source of food, cover, nesting and denning sites to which local wildlife are adapted.
3. There is a greater opportunity for organisms on which plant species depend to be present e.g., soil mycorrhiza, soil micro-organisms, and insects such as possible pollinators.
4. Native species express the local character of the area and integrate well with the natural landscape. A mixture of well-established native species is aesthetically pleasing. For example, the roadsides of certain areas in Texas are well known for their native wildflowers. Because the native species are also effective in preventing erosion, screening unattractive sites and do not require spraying or mowing, interest is increasing in using stands of native species along roadways in other areas (Ode 1972). In certain areas, commercially available native seed species adapted to local growing conditions may be required to maintain the pre-disturbance diversity of the prairie vegetation (Special Areas Board et al. 1992). Unfortunately, native forbs, although an important part of natural grassland plant communities, have often been ignored in revegetation programs because of the scarcity of commercial seed sources and high costs (Duebbert et al. 1981).
5. Native species in a pasture setting provide excellent summer and fall forage because of their growth and curing characteristics (Trottier 1992). The amount of forage a species produces is a good indication of its relative aggressiveness and ability to compete with weeds (Wilson 1972).
6. Native grasses may be particularly suitable for strip mine reclamation as the roots of some grasses will penetrate the soil to depths of 200 cm or more and increase soil friability (Hole and Nielsen 1970). As these roots decay, they increase the organic matter content of the soil and the above ground parts form a cover which decreases runoff, conserves soil moisture and can produce extensive biomass accumulation (Rodgers and Anderson 1988).

Some of the disadvantages of using native species in reclamation are that they are generally less available and more costly than agronomic, and often require specialized machinery for seeding and harvest (Collicutt and Morgan 1990;

Andersen, pers. comm. 1992). They frequently exhibit limited seed production and/or produce seed at irregular intervals (Romo and Lawrence 1990). Germination rates are also often low (Andersen, pers. comm. 1992). A slow rate of establishment may allow weeds to become a problem in the first few years after planting, while the native species are placing their energy into root rather than shoot growth (Adams, pers. comm. 1992).

Companion or nurse crops (usually annuals such as fall rye or barley) may be seeded with species expected to make a longer-lasting contribution to the reclamation of a site. The potential benefits of companion crops in the reclamation of native grasslands are that they may provide erosion control while slower growing native species are becoming established. They also provide some degree of protection to the slower establishing species, from drying winds, solar radiation, and weeds. Where sown with native species, less of the expensive native seed is generally required (Romo and Lawrence 1990).

Companion crops can also provide grazing, hay or grain in the year of forage establishment. Stubble from annual cereals helps to trap snow in the winter, and thus provide more moisture (Saskatchewan Agriculture Development Fund, n.d.).

The disadvantages of companion crops are that they compete with the long-term seedlings for water, light and nutrients. Competition from the companion crop can be minimized by: seeding the companion crop at half the normal rate; seeding the forage into firm soil in alternate or cross-seeded rows after the companion crop has been seeded; using fertilizer sparingly to avoid heavy growth; harvesting the companion crop early; and, removing the crop residue promptly (Alberta Agriculture 1978).

Although annual cereals are frequently used as companion crops, native species have been used in tall grass prairies and had the advantages of longer weed displacement, and production of less allelopathic affects on desired prairie species (Schwarzmeier 1972). Useful native companion crop species are those which intercept relatively little light and have shallow but dense root systems, therefore differing from most potential climax grasses and forbs in the community. It is also advisable to duplicate grassland successional stages which would normally occur within the ecoregion where revegetation is being attempted (Schwarzmeier 1972).

The success of using native species as companion crops in tall grass prairies in the U.S. suggests that further investigation in mixed and fescue prairies would be beneficial. However where moisture is limiting this technique may be detrimental (Vallentine 1989a).

Table 14 provides some appropriate native species for reclamation in the western Canadian prairies. Additional information on the suitability of various native (and agronomic) species for particular site conditions is available from a wide variety of sources such as Alberta Agriculture (1978, 1990a), Hardy BBT (1989), and Holzworth and Lacey (1991).

Table 14. Native Species Recommended for Reclamation in Western Canadian Prairies.

Species	Tallgrass Prairie	Fescue Prairie	Mixed Prairie	Dry Mixed Prairie
Needle and Thread ** (*Stipa comata*)			x	x
Green Needle Grass (*Stipa viridula*)	x	x	x	
Western Wheatgrass (*Agropyron smithii*)	x		x	x
Slender Wheatgrass (*Agropyron trachycaulum*)		x	x	
Northern Wheatgrass (*Agropyron dasystachyum*)		x	x	x
Streambank Wheatgrass (*Agropyron dasystachyum* var. *riparium*)	x	x		
Bluebunch Wheatgrass (*Agropyron spicatum*)		x		
June Grass (*Koeleria macrantha*)	x	x	x	x
Sand Grass (*Calamovilfa longifolia*)			x	x
Rough Fescue (*Festuca scabrella*)		x	x	
Big Bluestem (*Andropogon gerardii*)	x		x	
Little Bluestem (*Schizachyrium scoparium*)	x		x	
Blue Grama Grass (*Bouteloua gracilis*)	x		x	x
Indian Grass (*Sorghastrum nutans*)	x			
Tufted Hairgrass* (*Deschampsia cespitosa*)		x		
Reed Canary Grass* (*Phalaris arundinacea*)		x		

continued . . .

Table 14. Concluded.

Species	Tallgrass Prairie	Fescue Prairie	Mixed Prairie	Dry Mixed Prairie
Sideoats Grama (*Bouteloua curtipendula*)	x			
Fringed Brome (*Bromus ciliatus*)		x	x	
Porcupine Grass (*Stipa spartea*)	x	x	x	
Switch Grass (*Panicum virgatum*)	x			
Tall Dropseed (*Sporobolus asper*)	x			

* Adapted to wet meadow conditions
** Taxonomy based on Moss (1983)

Source: Duebbert et al. 1981; Hardy BBT 1989; Tannas, pers. comm. 1992; Trottier 1992; Wilkinson, pers. comm. 1992.

6.5.2 Seed and Propagule Availability

Seeds and propagules, such as rhizomes or cuttings, for restoring or reclaiming native grassland may be available on site, in the vicinity, or from seed companies, growers or research organizations. The nature of the propagule supply can influence both the rate and, at least over the short term, the direction of succession (Redente and Cook 1986).

6.5.2.1 On Site and In Vicinity. Depending on the extent of the area to be reclaimed and the nature of the surrounding vegetation, disturbed sites can revegetate naturally through encroachment of neighbouring propagules as demonstrated in Colorado (Redente and Cook 1986). It appears feasible where the disturbance affects only a small area, where the adjacent vegetation is desirable, and where weed invasion is not likely to be a problem. The advantage of this method of revegetation is that it is inexpensive and requires little labour. The disadvantages are that it may be slow, there is no input into species selection, and weeds may become a serious problem before slower-growing native perennials can establish (although mowing could likely alleviate this to some extent). In addition, the need to control erosion will entail further costs. The natural migration of propagules to disturbed sites is often erratic or compositionally undesirable and therefore may be augmented by various propagule supply practises (Redente and Cook 1986).

Where an area of diverse native grassland is to be disturbed, seed can be harvested directly on site or in the vicinity to use in subsequent reclamation (Collicutt and Morgan 1991). Harvesting has some inherent difficulties in that native seeds often ripen irregularly, in small quantity, over a short period of time, and occur close to the ground (Zimmerman 1972). Nonetheless, harvesting is widely practised for reclamation and restoration projects (Collicutt and Morgan 1991). Conservation of the disturbed topsoil will also allow propagules and rhizomes to provide a source of revegetation materials.

In a survey of 44 American commercial native seed producers, Cackler et al. (1983) found that 85% still used hand-harvesting to a significant degree to obtain seed. However this is not usually feasible for large undertakings. Conventional agricultural equipment such as combines and swathers can be adapted to harvest native seed (Dunn 1988; Schumacher 1988; Tober 1988 and others). Some models of Gleaner-produced combines now have superior sieve and cylinder configurations for separating native grass seed (Trottier 1992).

Much attention has been given in recent years to developing hand-held and mechanized seed strippers (Mahler 1988). Hand-held seed strippers are usually based on a gasoline-powered motor ("weed-eater") with an attached metal box and a collecting bag (Collicut and Morgan 1991). Seed heads cut by the rotating string-line are funnelled by the box into the collecting bag attached to the back opening of the box. It is advisable to note all species harvested and their dominance in the stand (e.g., dominant, significant, small or trace). A hand-held seed stripper similar to that developed by Mahler, has been recently adapted by Morgan and Associates in Manitoba (Morgan, pers. comm. 1992).

The advantage of these machines is that they are portable, inexpensive, easily constructed, can target selected species and can be used on steep, rugged terrain that large machinery could not traverse. The process may require repeat trips to an area to take into account different seed maturing dates. Disadvantages of this method are that a competent botanist or agrologist is required to determine which collected seed belongs to which species of plant, the process is generally labour intensive for large areas, and considerable quantity of weed seeds can be inadvertently collected. Grass scythes are also used for hand harvesting but this method is more laborious.

A number of custom-designed mechanical seed strippers are also available. These machines have revolving brushes or reels to strip the seeds off plants without cutting off the seed heads, as occurs in direct combining (Collicutt and Morgan 1991). They harvest the seed cleanly and collect only ripe seed (Heilman 1988). Therefore the field should be harvested several times over the extended period of time that ripening of most native perennial grasses occurs. Seed strippers can also be mounted on the front of a tractor (Mahler 1988; Mahler and Walther 1989) or be pulled behind (Collicutt and Morgan 1991). To increase the total number of species in seed mixtures, combined or mechanically harvested seed could be mixed with hand-harvested seed of

selected desirable species. Despite these innovations, for species such as rough fescue which may only flower and produce seed once every ten years, the problem of seed harvesting remains (Hermesh, pers. comm. 1992). More research is required on the condition under which this species produces seed and the development of management practices to accommodate this phenomenon.

Depending on the type of seed harvested, method of harvesting, the number of weed seeds in the harvested seed and the method of seeding to be used, the seed may need to be cleaned. Using such devices as hammer mills, fanning mills, indent mills and air-jet debearders to remove the awns or glumes of some species may allow them to be seeded with a conventional grass seeder (Collicutt and Morgan 1990; Jacobson 1988; Vogt 1988; Weber 1939; Wiedemann 1988).

Hand or mechanically harvested seed may be increased in multiplier plots by custom growers prior to seeding in a reclamation or restoration project. Private growers and government agencies such as the Alberta Environmental Centre at Vegreville are currently multiplying the seed of numerous grasses and forbs so that they will be more available for reclamation/restoration projects in Alberta. Certain private growers presently custom grow desired seeds for specific projects. When multiplying seed, it is advisable to have replicate plots to avoid being wiped out by natural disasters such as hail (Tannas, pers. comm. 1992).

Most native prairie perennial grasses and forbs display a period of dormancy (Drobney 1983; Greene and Curtis 1950; Robocker et al. 1953) to ensure that the seed will germinate at the optimum time for establishment. For most plants, this means timing germination to coincide with the period of most abundant soil moisture. In the prairies this usually occurs in the spring following the year in which the seed ripened. Seeds can remain dormant for long periods if appropriate conditions for germination are not met (Raven et al. 1976).

To break this period of dormancy, seeds of several, but not all native species must be stratified, (defined as a period of exposure to cool (1 to 10°C), moist conditions). Stratification initiates physiological processes that terminate dormancy (Raven et al. 1976). Length of stratification required varies with the species but usually is in excess of one month for most prairie grasses and forbs (Eddleman 1980; Nuzzo 1978). Seeds of some prairie species may be stratified by adding a small amount of water, or mixing them with a small amount of moist vermiculite or sand and storing them in a refrigerator or cooler for the proper length of time (Nuzzo 1978; Ode 1972; Schramm 1976). Moeller (1973) allowed seeds to stratify naturally by burying them, in bags, in the ground. Fall seeding also allows natural stratification over winter (Rock 1981).

Seeds with hard, impermeable seed coats, such as some legumes, may also require scarification. This involves penetration of the seed coat, often done by nicking with a sharp object, treatment with an acid solution, or rubbing with sandpaper to make the seed coat permeable (Raven et al. 1976). Dickerson et al. (1981) mentions the use of hammer mills to scarify large amounts of seed. Fall seeding promotes

with an acid solution, or rubbing with sandpaper to make the seed coat permeable (Raven et al. 1976). Dickerson et al. (1981) mentions the use of hammer mills to scarify large amounts of seed. Fall seeding promotes scarification through frost action and soil movement in winter (Rock 1981). In arid and semi-arid ecoregions, seed germination and seedling establishment are the most vulnerable stages in the development of both natural and synthetic plant communities (Call and Roundy 1991).

The question of "how far from the reclaimed area should propagules be taken?" has received some study. Populations of plants exist in genetically differentiated ecotypes which develop in response to elevation, precipitation, temperature, growing season, soil and topographic conditions of a particular habitat (Schaller and Sutton 1978). These species may not be able to adapt well to conditions at another site and illustrates a critical point in developing strategies to reclaim native grasslands.

Varying distances are given by different sources ranging from no more than 40 km from point of origin (Packard 1990), to up to 800 km from point of origin (Holzworth and Lacey 1991). Such suggestions are unsubstantiated within Alberta by scientific study and must be considered preliminary at this time. Ecotypic variability, microadaptation and the interaction of genotype and environment have resulted in a complexity of factors which influence the distance over which species adaptations remain within their range of tolerance. Holzworth and Lacey (1991) suggest that non-certified, common seed of an indigenous, native species can be seeded within a range of 800 km south of the collection site, or 480 km in other directions without serious adaptation problems. Allowable distance for east-west movement is influenced primarily by precipitation and elevation. Romo and Lawrence (1990) proposed that plants of a certain ecotype can be moved 400 to 500 km north and 150 to 250 km south to similar sites and essentially perform as they did in their original location. Usually southern plants moved to northern location will be greener and leafier because of more effective moisture but produce few, if any viable seeds, while northern plants moved south do not take advantage of the longer growing season (Romo and Lawrence 1990). Clearly further research is required in this area.

Using non-local ecotypes may result in less competitive plants, loss of genetic diversity and hybridization with local types. This hybridization may eliminate characteristics specific to the local population before they can be studied and understood (Rock 1981).

6.5.2.2 From Seed Companies/Growers. While native seed is still not as readily available as seed of agronomic species, increased demand and knowledge of growing and harvesting techniques has resulted in a greater supply of native seed from commercial sources. Native seed has been available in the United States, for some time, however, Canadian grown seed is, by comparison, extremely limited. Native grass seeds have been available for some time, however native forb seed has only recently been available.

Certified seed is available for some varieties of native species. Using certified seed (when available) helps to ensure specific genetic characteristics, and helps to minimize the risk of introducing weed seeds (Loewen, pers. comm. 1992). Non-certified common seed may come from different areas and be less well-adapted (Holzworth and Lacey 1991).

6.5.3 Season of Revegetation

It is generally accepted that the best season to seed is prior to the season that receives the most dependable precipitation (Cook et al. 1974; Ries et al. 1987a; Vallentine 1989a). In Alberta, most seeding (and revegetation by other means) takes place in the early spring or late fall to take advantage of peak rainfall levels in late May and June (Adams, pers. comm. 1992).

Work in the U.S. by Vallentine (1989a) suggest that spring seeding should preferably be completed early, but not so early that the seedlings may be subjected to heavy frosts. One of the main disadvantages of spring seeding is that late frosts or wet conditions can delay seeding until the weather becomes hot and dry and the seedlings are then subjected to severe heat and moisture stress. Vallentine states that, for spring plantings, a favourable growing period of 40 to 60 days will generally assure successful stand establishment.

Late fall seeding allows adequate time for seedbed preparation, seeds are scarified by frost and soil movement, and seed dormancy is broken by the cool, moist conditions over winter. Seedlings can take advantage of cool, wet conditions in the spring and have a longer growing period (Romo and Lawrence 1990; Adams, pers. comm. 1992). Unfortunately, no experimental data were found in the literature examining these topics in detail. One of the chief disadvantages of fall seeding is that a prolonged warm spell in the fall can promote germination of the seed which can then be killed by subsequent cold weather, particularly if there is little snow cover over winter.

Cool-season grasses are suitable for seeding in either early spring or late fall, as they will germinate and emerge at lower temperatures than warm-season grasses. Warm-season grasses are best seeded in mid to late spring as the seedlings are sensitive to late fall and early spring frost (Romo and Lawrence 1990).

In tall grass prairie restoration projects in Manitoba, spring seeding was more successful than fall seeding. The spring seeded plots showed better germination of grasses and forbs and weed problems were less severe (Morgan, pers. comm. 1992). Spring seeding is also preferred by the Alberta Environmental Centre at Vegreville to take advantage of the early spring moisture

should dictate the time and method of planting (Cook et al. 1974).

The above discussion applies to seeding native plants. The appropriate season of revegetation by other methods such as spreading harvested seed/straw, sprigging, sodding and salvage of existing plant materials is discussed in the following section under the appropriate headings.

6.5.4 Methods

The methods and techniques currently being applied in native grassland reclamation and restoration are in various stages of development and experimentation. As previously discussed, many approaches lack the benefit of detailed experimental design and extensive field trial research, particularly over a sufficient period of time to confidently document long-term results. The variability of biophysical site conditions and ecotypic adaptation of native grassland species presents another challenge in the development of these techniques which suggests further research is required in these areas.

Four main methods of revegetation are currently being used to reclaim native grassland. These are seeding, including drill seeding, imprinting, broadcast seeding and hydroseeding; spreading harvested seed/straw; sprigging; and salvage of existing materials (including sodding).

Each method requires appropriate species selection, for site conditions, adequate site preparation, and suitable timing of operations. Careful maintenance and diligent monitoring will increase the probability of successful reclamation or restoration. Patience is required as establishment of native species is a long term process, particularly in drier regions.

No comprehensive guidelines specifically for seeding native grasslands were encountered during this review. The following recommendations, developed for seeding agronomic species, are however thought to be generally applicable to seeding native grasslands:

1. appropriate species selection of locally adapted species using certified seed where possible;
2. adequate seedbed preparation. A raked, firm seedbed which permits uniform, shallow coverage and promotes good seed/soil contact is preferred;
3. proper timing of seeding operations;
4. use of suitable equipment and seeding rates based on our current level of knowledge;
5. proper depth of seeding and covering the seed to avoid losses due to desiccation, predation, etc.;
6. suitable maintenance - although experimental trial data are limited, in some cases irrigation, use of mulches, fertilizer application, mowing or burning may enhance stand establishment;
7. it may be necessary to destroy competing vegetation prior to seeding.

Whether or not an area is suitable for seeding depends on: the kinds and amounts of plants remaining, local climate and soil conditions, supplemental treatments that may be required in the restoration process, accessibility and cost (Vallentine 1989a). Seeding is a more expensive method of reclaiming a site than natural succession, however more input is possible into species selection.

Seeding rates vary with location, technique and species seeded (Romo and Lawrence 1990). Sparser seedings can result in more robust plants in some instances and can allow for some invasion of adjacent native species. Seeding rates should consider how much natural diversification of the vegetation community is desired. If none is desired, a heavy seeding may be preferred, with strong fertilization programs to promote the rapid establishment of a relatively closed grass community. If some natural diversification is desired, the seed density and fertilizer programs should be less intensive, allowing some space for natural revegetation to intermix with planned revegetation species (Wathern and Gilbert 1979).

6.5.4.1 Drill Seeding and Interseeding. Drill seeding is the preferred method of revegetation on native rangelands primarily because of the degree of control which is affected in seeding rates and seed placement beneath the soil surface (Ries et al. 1987b; Vallentine 1989a; Walker, pers. comm. 1992). While conventional seed drills have been used for seeding native species, problems have resulted, particularly from awned seeds "bridging" and preventing uniform seed flow. In recent years seed drills have been developed specifically for native species. These include the Nesbit drill (which can seed forbs as well as grass seeds and is well-suited to sandy or sandy loam soils), the Nobel drill (adapted for use with compacted soils or where gravelly soils occur on gentle slopes), the Truax drills, double disc drills, rangeland single disc deep-furrow drills, John Deere Van Brunt single disc semi-deep furrow drills (preferred for clay loam soils which have been previously tilled or summerfallowed), and the new drills currently being developed by Morgan and Associates in Manitoba (Morgan, pers. comm. 1992).

The preferred characteristics of drills used for native seeding include the following:

1. ability to withstand adverse terrain, rocks and brush with minimum maintenance;
2. separate boxes for large, small and fluffy seeds;
3. agitator in seedbox to prevent seed and trash bridging over the seeder openings;
4. precise metering of seed (force feed usually better than gravity feed except for fluffy seed);
5. baffles to maintain distribution of seed in seedboxes on steep slopes;
6. disc openers equipped with band-type regulators;
7. flexible equipment to allow individual planters to adjust to irregular seed;

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6. disc openers equipped with band-type regulators;
7. flexible equipment to allow individual planters to adjust to irregular seed;
8. mechanism for rapid and accurate setting of seeding rates; and,
9. wide packer wheels to decrease sinking, especially on sandy soils.

Seedbed preparation is imperative to the success and uniformity of stand establishment (Romo and Lawrence 1990). Proper equipment and seeding techniques are most critical in areas of low precipitation and if small, light seeds are being planted. When seeding small seeded grasses, it is beneficial to mix in autoclaved (sterilized by high heat) wheat seeds for bulk to prevent bridging (Smreciu, pers. comm. 1992). Sand or other coarse material will ensure even distribution (Rock 1977), and help carry light, fluffy grass seeds through the drill (Trottier 1992). This carrier material should be added at approximately half the bulk grass seeding weight (Ducks Unlimited, no date). Similarly, partially dried vermiculite has been mixed with forb seeds to facilitate their movement through the seed drill (Schramm 1972).

The rates at which seeds are sown for restoration seems to have evolved largely on a trial-and-error basis (Collicutt and Morgan 1990). In the tall grass prairie, recommended rates range from 20 to 24 kg/ha for broadcast application and 10 to 12 kg/ha for drill application (Bowen 1990; McLain 1986; Rock 1981; Schramm 1976). The basis for such rates however is questioned by Collicutt and Morgan (1990) who state that " Much more research needs to be conducted if it is to be understood why these rates appear to be successful or perhaps if in fact they are not the optimum values". A similar argument can be made for seeding rates in other prairie ecoregions.

The rate of seeding is dependent on seed type, size and germination percentage. For planting, the quantity of viable seed is generally expressed as kilograms/hectare (or pounds/acre). This value represents the actual number of seeds per unit area of the soil surface and thus, when planting a small-seeded species, fewer kg are required per hectare to achieve the desired seed number per unit area and, conversely, more kg per hectare are required for large-seeded species (Cook et al. 1974; Duebbert et al. 1981).

In order to account for seed quality the grass seeding rates should be expressed as pure live seed (PLS) in kilograms/hectare. The percentage of pure live seed delivered to the soil medium is expressed by the formula:

$$\text{Pure Live Seed} = \%\ \text{germination} \times \%\ \text{purity}$$

For example, a 23 kg bag of seed marked 90% germination and 90% purity contains:

90% x 90% = 81% pls, and

81% pls x 23 kg = approximately

18.6 kg pls (Heady 1975).

Drills should be calibrated to deliver the desired amount of pure live seed per square metre and place it at the proper depth. They should also be calibrated for every mixture type to ensure proper seeding rates. Calibration can be performed by jacking up the drill and turning the drive wheel for a set number of revolutions, catching the seed flowing out, and weighing it (Vallentine 1971).

For a tall grass restoration prairie project in Manitoba, Collicutt and Morgan (1991) used 0.6 kg/ha (0.5 kg/ha grasses plus 0.1 kg/ha forbs), while Cook et al. (1974) suggest 4.5 to 5.75 kg/ha (4 to 5 lb/acre) for small seeds and 8 to 11.25 kg/ha (7 to 10 lb/acre) for large seed based on pure live seed in the Northern Great Plains. Seeding rates are normally increased for small seeded species and those with poor germination.

Proper depth of planting is essential to successful stand establishment of seeded grasses and legumes. Generally it is recommended that native grasses are seeded from 1.0 to 2.5 cm deep for maximum seedling establishment (Vallentine 1989b). The kind and size of seed, soil texture, and moisture conditions are the principal factors that influence seeding depth. Grass seed should be planted at a depth of 1.25 to 1.88 cm in medium to fine textured soils and approximately 1.25 to 2.5 cm in coarse textured sandy soils (Duebbert et al. 1981).

Depth of planting should be proportional to the size and weight of the seed being planted (Romo and Lawrence 1990). Small seeded grasses, such as blue grama grass should be seeded at shallower depths (1.0 cm or less) than larger seeded species such as wheat grasses and green needle grass which can tolerate depths of 1.0 to 2.5 cm (Ries et al. 1987b). Seeding too deep delays emergence and reduces total emergence of new plants, while seeding too shallow results in loss of seed due to desiccation, removal by wildlife and erosion (Cook et al. 1974). As moisture decreases, seeding depth should increase, however seed should never be placed deeper than five times its diameter (Alberta Agriculture 1990b).

Packing or rolling the soil after seeding is necessary to ensure the soil is in firm contact with the seed, permitting water uptake by capillary action (Alberta Agriculture 1990b). Drill seeding, followed by cultipacking, is a preferred method of seeding because it provides proper placement and covering of the seed in a single operation (Ries et al. 1987; Vallentine 1989a).

In the reclamation of surface mined land in Colorado, Cook et al. (1974) recommend a drill row spacing of 15.0 to 17.5 cm (6 to 7 inches) for semi-deep furrows and a spacing of 30.0 to 35.0 cm (12 to 14 inches) for deep furrows, otherwise the seed is covered too deeply when soil is thrown aside by the adjacent furrow opener. Wider spacings are undesirable since they allow competition from weeds between the rows, thereby prolonging the establishment of the native grasses. Narrower spacings help to reduce unde-

sirable species which might be present and promote higher production. Romo and Lawrence (1990) suggest that drill spacing can vary from 15 to 30 cm, using the wider spacing where moisture is limited. Proper row spacing is important to eliminate inter- and intra- specific competition for water and nutrients. Correct row width allows faster stand establishment and the highest production under dryland conditions (Holzworth and Lacey 1991).

The advantages of drill seeding (adapted from Sims et al. 1984) are:

1. improved soil moisture availability;
2. more uniform stands;
3. more wind protection for seeds compared to broadcasting;
4. rapid production;
5. less seed required per unit area than broadcast seeding;
6. controlled seeding rate;
7. controlled depth of sowing; and,
8. the ability to spread fertilizer and other amendments at the same time.

The disadvantages of drill seeding are;

1. the machinery is mainly restricted to uniform, near-level sites;
2. cost and time are often increased over such methods as broadcasting, although broadcasting may require up to twice as much seed; and,
3. in native grassland restoration projects, a plant community in visible rows is undesirable. Schramm (1972) has suggested making more than one pass over a field, in different directions, to alleviate this problem.

Interseeding is a method used to introduce desirable plant species to a grassland by preparing only strips of the area for seeding. It relies on the eventual spread of the newly seeded species and is generally slow, because of competition between the seedlings and the existing vegetation. However, it may be preferred over seedbed preparation and seeding where: (1) soil erosion is a problem; (2) preparing a seedbed is impractical; or (3) the aim is to modify not replace the existing vegetation (Vallentine 1989a). It also has the advantage of being cheaper than trying to reseed an entire area. No-till attachments are available for seeding native grasses into sod to renovate grassland in poor condition. These drills can be borrowed or leased from Agriculture Canada Prairie Farm Rehabilitation Act offices, forage associations and some conservation districts (Trottier 1992).

6.5.4.2 Imprinting. Imprinting is a relatively new technique for tilling and planting which has been developed for arid and semi-arid regions of the world. It has been used successfully in the western U.S., primarily to renovate depleted rangelands.

Imprinting involves the use of a machine which imitates the action of animal's hooves on

soil. An angular tooth or foot creates funnel-shaped depressions in the soil surface. Most imprinting machines are constructed to resemble "large rolling pins with a waffled surface" (Dixon 1988) and are pulled by a tractor. Seeds are scattered, often from a broadcast seeder mounted just ahead of the roller and are pressed into the imprinted surface.

The depressions formed increase the percolation of water into the soil, decrease runoff and funnel water to sites where seed and mulch are likely to accumulate (Dixon 1988). According to Anderson (1981) rainfall is concentrated and in effect, doubled and a minimum of rainfall is utilized to a maximum extent. The imprinting pattern forms interconnected watershedding and water-absorbing v-shaped furrows, or a rain-fed microfurrow, irrigation system. Debris is mulched into the soil (Anderson 1981).

Imprinting differs from conventional tillage in that the soil is not turned over and therefore disruption of the surface litter is minimized. In contrast to discing and drilling, which leaves loose soil which is subject to wind and water erosion, imprinting results in a firm seedbed, and reduces soil erosion by keeping rainwater where it falls (Anderson 1981). Because the machine is of simple construction, it is relatively inexpensive, durable and maintenance-free. Dixon (1988) suggests that imprinting would be effective in revegetating dry prairies and dunes as well as non-prairie sites where adequate water supply is a problem.

Currently twelve different geometric imprinting patterns have been designed, each for different conditions and objectives (Anderson 1981). NOVA Corporation of Alberta has used this method in pipeline reclamation projects and has found that the best results occur in finer textured soils with moderate soil moisture levels (Lees, pers. comm. 1992). It is relatively inexpensive to use compared to straw crimping, hydromulching or tackifying. A specialized piece of equipment known as a Hodder Gouger has also been successfully used on sandy soils within southern Alberta (Lees, pers. comm. 1992).

6.5.4.3 Broadcast Seeding. Broadcasting is any method of seeding that scatters the seed directly on the soil surface. It is designed to simulate natural dissemination by wind and may be done by hand, by rotary or box-type seeders, or by airplanes or helicopters.

Seed should be broadcast onto a roughened seedbed and then covered by soil using rakes, harrows, discs or by pulling a small sheepsfoot roller over the seeded area. Running a small tracked vehicle over the area may also cover the seed and it will compact loose or freshly tilled soil. This procedure should not be done when soils are fine-textured and prone to compaction (Cook et al. 1974).

If mulches are used in conjunction with broadcast seeding in dry areas the best results can be obtained by broadcast seeding, covering with soil, and then applying the mulch (Cook et al. 1974).

When hand broadcasting, one should try to seed slowly and cover each area in two directions. If forbs are included in the mix, this seed

can be concentrated in high priority areas or spread throughout the site. When forbs are added to a revegetation program, about three to five seeds per 0.5 square metre (1 sq. ft.) should be allowed (Cook et al. 1974). Much of this seed is small and should be spread thinly to achieve best results. Seeding should be followed with a light raking for best results (Prairie Restorations, Inc. 1992).

Prairie Restorations, Inc. (1992) suggest broadcast seeding rates for prairie restoration projects in Minnesota of 20.5 to 25 kg/ha (18 to 22 lb/acre) for grass seed and 1.3 to 5.8 kg/ha (1 to 5 lb/acre) for wildflower seed.

Broadcast seeding has been successfully used in tall grass prairie restoration projects in Manitoba by a two person team hand broadcasting seed from the back of a truck, followed by a drag chain to cover the seed (Morgan, pers. comm. 1992). Schiechtl (1980) has recommended the mixing of small, light seed with amendments such as sand to produce a more even spread.

In summary, the advantages of broadcast seeding are:

1. easier to use on rough terrain, and steep slopes;
2. relatively inexpensive;
3. fertilizer can be spread simultaneously; and,
4. often an effective way of establishing a diverse community (DePuit and Coenenberg 1979).

The disadvantages of broadcast seeding are:

1. larger amounts of seed are required than for drill seeding (usually about twice the amount). Poor sites, such as those which have low quality soil conditions or rough terrain, require an even higher amount of seed;
2. uneven dispersal (this could be alleviated by applying at low wind speeds); and,
3. unless the seed is covered, it is exposed to erosion, predation and desiccation which can result in lower establishment rates (Sims et al. 1984).

6.5.4.4 Hydroseeding. Hydroseeding or hydraulic seeding involves the application of a slurry of seed and water to soil. It is primarily used as an erosion control technique on steep slopes or thin soils. The slurry may also contain sprigs of plant material instead of seeds, and amendments such as fertilizer, mulch material, and/or neutralizer. The hydroseeding mixture must be constantly agitated to ensure an even consistency (Schiechtl 1980).

The advantages of hydroseeding as summarized by Sims et al. (1984) include the following:

1. it is useful for steep or wet areas where use of other machinery is not feasible (it is often utilized to seed steep slopes along highways);

2. it is expensive (cost may range from $2 800 to $3 800 per hectare - Lees, pers. comm. 1992);
3. seed can be damaged by the hydroseeding process (Hodder 1970);
4. fertilizers in the slurry can interfere with germination and normal root and shoot development (Hodder 1970);
5. seeds may get "hung up" in the mulch and not be placed in contact with the soil. Collicutt (pers. comm. 1992) suggests that hydroseeding followed by hydromulching may help to hold the seed closer to the soil and thus alleviate this problem; and,
6. the area to be hydroseeded generally requires the exclusion of livestock grazing during initial vegetation establishment.

Hydroseeding does not appear to have been widely used in native grassland reclamation and is not recommended by some prairie restorationists (Bowen, pers. comm. 1992) primarily because of the problem of poor seed/soil contact.

6.5.4.5 Spreading Harvested Seed/Straw. The so-called "hay method" of re-establishing grasses was originated in Kansas in 1937, but until recently there has been little information available in the literature on this technique. It has attracted more interest lately, and has been used successfully in the northern United States. Hay is harvested when the majority of the seeds of the desired species are ripe and the resultant mulch is spread over a smooth and weed-free seedbed or over stubble. The mulch is anchored by packing with a subsurface packer, covered with a disk-drill set to a shallow depth, or tacked down in some manner (Romo and Lawrence 1990). Hay or straw material Application rates range from 1500 kg/ha to 2000 kg/ha and may be effective in soil stabilization for a period of 12 to 18 months after application (Lees, pers. comm. 1992). The mulch should be spread as uniformly as possible, prior to the season of greatest precipitation. Rates of application depend on type of species contained in the mulch; amount of hay and seed produced; site and climate characteristics; and, potential for erosion (Romo and Lawrence 1990).

According to Romo and Lawrence (1990), factors which must be taken into account when this technique is being considered include:

1. native species seed production is variable from year to year and site to site and therefore optimal harvest time is also variable;
2. generally one or a few species will be dominant in the mix;
3. exotic species in the mulch, and cultivars of native species seeded in the plot to be revegetated, will likely be more competitive than native species present in the mulch; and,
4. tackifiers or crimping will likely be necessary to hold the mulch in

place where there is a potential for wind erosion.

Whitman (1977) renovated rangeland in North Dakota affected by mining activities by seeding an annual species followed one year later by mulching late-cut prairie hay and spreading it over the stubble of the annual crop. The mulch was subsequently anchored by discing. This method produced a plant community similar to that which existed before mining.

Ries et al. (1980) conducted a study in Mandan, North Dakota to determine the relationships of range condition and harvest date to the amount and kinds of seeds present in the mulch. Samples from excellent, good and fair ranges were collected over five different harvest dates (approximately the first of each month from June to October). By knowing the range condition and harvest date of prairie hay, some control could be exerted on the amounts and kinds of seeds available in the hay. They discovered that the abundance of 15 species in the mulched hay was related to range condition where the hay was harvested, and the abundance of 21 species in the mulched hay was related to the date of harvest.

The condition of the rangeland affected species composition. For example, needle-and-thread was most common in good condition range, western wheatgrass was most common in excellent condition range, and june grass was most common in fair condition range. Prairie hay from a range in fair condition contained the most observed perennial grasses, perennial forbs, annual grasses, and total plants, likely because it consisted of high seed-producing short-lived perennials and annuals. The most abundant annual forbs were noted in association with hay harvested from excellent condition range. The greatest number of seedlings were found associated with fair and excellent condition ranges where harvest was undertaken in July. The researchers concluded that the numbers of seeds present can be quite high and that harvest date and range condition governed the kind and amount of potential seedlings contained in prairie hay.

To obtain hay with the highest number of desired species, one should harvest in a year when conditions are favourable for seed production of that species. It is therefore important to know how long hay can be stored without loss of viability. A corollary investigation on the effects of storage on the viability of seed in prairie hay was also conducted (Ries and Hofmann 1983c). Storing hay for one year did not decrease the number of established seedlings from prairie hay used as a seed source in greenhouse experiments. In fact, some species had higher establishment after storage (june grass, thread-leaf sedge, fringed sage and yellow whitlow-wort). Some species became established from prairie hay only after storage (purple prairie clover, Lambert crazyweed and birdsfoot trefoil), indicating a possible need for an after-ripening period.

The Alberta Environmental Centre (Vegreville) used native hay as a mulch on a small project in the hope that seeds of the species would become established. Hay was cut from two pastures (one composed predominantly of june grass and one mainly of rough fescue) when the seeds of these species were ripe. The hay was

baled and stored until spring, when it was spread liberally over areas where native seed mixtures were seeded, and held down with netting. The area is being monitored but no results are available as yet (Smreciu, pers. comm. 1992).

Some of the advantages of using spread harvested material as a seed source are (Ries et al. 1980; Romo and Lawrence 1990; Wenger 1941):

1. species diversity may be increased over conventional seeding;
2. seeds are supplied that are not commercially available;
3. the mulch can provide a supplemental seed source of locally adapted native seed;
4. if properly anchored, the hay mulch decreases erosion;
5. the mulch creates favourable microsites for seedling establishment by conserving soil moisture, increasing water infiltration, and decreasing soil crusting;
6. no specially designed equipment is necessary;
7. it is adapted to a wide range of site conditions and purposes such as landscaping, rangeland rejuvenation, and reclamation of parks, natural areas and surface-mined lands;
8. it is relatively inexpensive;
9. the process can accelerate natural succession; and,
10. using hay mulch as a revegetation method has a high success rate.

The disadvantages of spreading harvested seed/straw are (Ries et al. 1980): (1) it is labour intensive; and, (2) depending on climatic conditions, time of harvest, and species composition of the stand harvested, one species (not necessarily a desired species) may predominate in the mulch.

Ries et al. (1980) recommend harvesting prairie hay mulch from different site conditions and at different dates, and mixing this hay to obtain maximum diversity of species. They suggest related topics where further investigation is required, including seed dormancy mechanisms, further research on the effect of climate on species present and seed production, and documentation on which species can and cannot be established from a mulch.

6.5.4.6 Sprigging. In some environments, where seed production is sparse and erratic, using vegetation plugs to revegetate is a feasible option. These plugs may also be valuable in supplying soil with micro-organisms as well as accelerating invasion of native species (Bell and Meidinger 1977). Although sprigging has been used by Ducks Unlimited to revegetate low-lying, saline prairie areas in Saskatchewan (Wark, pers. comm. 1992), using sprigs from rhizomes and other material for vegetative propagation does not appear to be used much in reclamation of native grasslands, likely because of the high cost and the fact that many prairie species are not highly rhizomatous (Vallentine 1989b; Collicutt, pers. comm. 1992). Seeding seems to be a more effec-

tion on which species can and cannot be established from a mulch.

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6.5.4.7 Sodding. Sodding involves the removal and subsequent replacement of existing sod from an area to be disturbed. In some cases, sod may be taken from a similar plant community within the vicinity and placed on the area to be revegetated. Ideally sod replacement takes place as soon as possible after removal, however in some instances it may be necessary to store the sod for some time. Stored sod must be protected from desiccation and also tends to deteriorate with time. Although sodding does not appear to be widely practised as a reclamation technique in native grasslands in Alberta, the Special Areas Board et al. (1992) suggest that it should be considered in black soil zones with native plant cover.

Prairie restoration is being attempted in the tall grass prairie in Manitoba using sodding. In November, when dormant, a 0.8 hectare (2 acre) native grassland plot was cut into sections approximately 0.5 m square by 0.3 m deep (2 feet square by 1 foot deep). A specially designed machine with three parallel tempered steel cutting discs was used. The sods were picked up with a front end loader and placed with a fork lift on the area to be revegetated. Although 50% to 75% of the species survived, including many deep-rooted plants, weeds (mainly Canada thistle) proved to be a problem and the method was expensive (Collicutt, pers. comm. 1992). Within the fescue grassland ecoregion, similar removal of sod and replacement in association with a residential housing development proved to be successful both in a restoration sense as well as providing a focus for community involvement (Revel 1991).

The possible benefits of sodding as a restoration technique are that the species composition of the site can be maintained, no seed must be purchased, and, besides the actively growing plants, the sod also supplies soil micro-organisms, mycorrhiza and a latent seed source. For very small areas, no specialized equipment is required (Bunin et al. 1982).

Sodding appears to be too expensive and too laborious for consideration in most large scale native grassland reclamation projects. However it may be feasible as a technique to reclaim narrow, linear soil disturbances or small, high value sites. Other disadvantages of sodding are that:

Established plants in sod are more resistant to drought than seedlings as the mature plants can survive drought by becoming dormant. In addition, the soil volume which acts as a moisture source for seeds is very small compared to that for established plants with extensive root networks. Even in cut sod, the effective soil moisture reserve available to a plant is much larger than for a seed. The total water requirements for successful native grassland sodding are therefore less than for seeding.

Cutting sod decreases the effective water storage which the previously extensive root system had tapped. Therefore Bunin et al. (1982) suggest irrigating the sod before cutting and after laying. They recommend late winter (but non-frozen soil) or early spring for sod transplanting so that the spring precipitation would help establish roots and bind the sod to the subsoil.

Native grassland sodding is workable where there is sufficient soil-binding by vegetation (especially rhizomatous grasses) and is particularly suited to cooler locations because there is larger root biomass under these conditions (Sims et al. 1984). The vegetation characteristics required for successful native grassland sodding are sufficiently high plant cover, and enough plants with shallow roots or horizontal stems in the surface soil. Sod-forming plants such as bluestems, blue grama grass, western wheat grass and sedges have numerous rhizomes or stolons and are capable of good vegetative spread. Good surface soil binders include bluebunch wheat grass, blue grama grass, fringed sage, threadleaf sedge, and western wheat grass. Poor surface soil binders include: bluebunch wheat grass, green needlegrass, needle-and-thread, june grass, Sandberg bluegrass and sagebrush.

Successful sodding has been undertaken to reclaim mined land in Colstrip, Montana (Bunin et al. 1982). Sod was cut with a commercial sod cutter into pieces 5 to 6 cm deep, 45 cm wide and up to 8 m long. This sod was then rolled, transported on a flatbed truck and laid down with the long axes parallel to the contours. In the critical areas where continuous sod was laid, 3 to 4 cm overlaps facing downhill were used to aid in survival of the sod. Sodding was done as early in spring as possible and ended by July 1. If the sodding was done when the sod was dry, a hydroseeder was used to wet the sod the night before cutting. The sod took approximately 3 weeks to bind to the soil enough to withstand normal runoff. Initially a commercial product, Roll-lite was laid over the sod to protect it from water erosion.

Native grassland sodding is feasible only if the following conditions are met (adapted from Bunin et al. 1982):

1. the existing plant cover contains perennial vegetation in satisfactory range condition;
2. the existing perennial vegetation is appropriate for the anticipated end land use;
3. enough surface-soil binding plants exist on sites to be transplanted to ensure a sod which will hold together;

4. the soil is sufficiently consolidated and rock free to be cut and moved as sod strips;
5. sufficient water (natural or supplied) is available to wet the sod prior to cutting and once or twice after laying. The subsoil should not be watered prior to sod laying as this produces soil compaction;
6. the overburden or topsoil receiving the soil provides a favourable medium for root growth; and,
7. sufficient moisture is available to allow roots to bind to the substrate and plants to stabilize.

The advantages of sod transplanting were listed as: rapid recovery and re-establishment, minimization of erosion, preservation of the original soil and biotic systems and the establishment of an ecosystem native to the site. The major disadvantage was the expense, however it must be taken into account that the land may be used earlier for grazing than if it were seeded, there is less long-term maintenance and erosion, and improved aesthetics result (Bunin et al. 1982).

6.5.4.8 Mulches. Mulching studies have primarily been carried out in the eastern and mid-western United States (Sims et al. 1984). Mulching is reported to increase the success of establishing native species through enhanced germination (Fraser and Wolfe 1982; Ode 1970; Ries and Hofmann 1983a). An ideal mulch should hold the seed in place, should not inhibit the emergence of the seedling, should prevent erosion, should promote infiltration, insulate the seed from extreme temperature variation, and retain soil moisture (adapted from Fraser and Wolfe 1982).

Mulches may be particularly useful for preventing erosion, conserving soil moisture and providing a suitable seed bed for germination on difficult reclamation sites. Where annual precipitation is between 250 and 450 mm, especially on exposed south and west-facing slopes, mulches are highly conducive to seedling establishment (Cook et al. 1974). In areas where annual precipitation is higher, mulches are generally not required.

There are a number of different mulches which may be used and each has different benefits and disadvantages. Straw or hay mulches are commonly used as they are cheap, readily available, easy to apply and relatively effective. Typical straw or hay mulches can be spread by hand or applied with specific equipment (Fraser and Wolfe 1982), and should be distributed evenly over the soil and held in place by incorporation into the soil surface. This may be done by using a mulch tiller, a modified sheeps-foot roller, or an agricultural-type disc. The mulches should be clean and free from weeds to reduce the potential for competition with native vegetation seedlings (Cook et al. 1974). Ideally a straw or hay mulch should have long, wiry stems. A tackifier is recommended in erosion prone areas to hold the mulch in place.

A straw crimper has been tested by Foothills Pipelines Ltd. in the Saskatchewan Sand Hills and has been effective in soil stabilization and promoting revegetation on steep valley walls.

Bundles of straw are forced into the soil which decreases wind and water erosion on the soil surface and creates favourable microenvironments for newly planted seed (Exner et al. 1982).

In Montana, a straw mulch with an asphalt binder proved to be an effective and economical mulching treatment for low-wind highway revegetation treatments (Hodder 1970). This mulch provided lower soil temperatures, maintained adequate moisture for seed establishment and decreased erosion.

Decomposition of straw mulches has been shown to increase the total numbers of microarthropods, and in mine spoils, populations of bacteria increased more rapidly on sites with organic amendments (Whitford 1988).

Other similar mulch mat materials are wood fibre, coconut fibre, nylon materials and other synthetics.

Another popular type of mulching technique is hydromulching, which involves applying a ground wood fibre or paper product in a water slurry with a specifically designed machine (hydromulcher). Hydromulching is frequently used on steep slopes that could not otherwise be mulched. Two main disadvantages are the cost and the need for water. In the past, seed, fertilizer and mulch were applied in one operation but this practise has generally lost favour because the seed often became suspended in the mulch and lost contact with the soil. Hydromulches with longer fibres are generally most useful. To improve the effectiveness of hydromulches, a tackifier such as asphalt or plastic emulsions, or organic glues may be used (Fraser and Wolfe 1982). Where heavy runoff is likely, mat mulches perform better for controlling erosion and aiding cover establishment (Ringe and Graves 1987).

In summary, mulches significantly enhance the establishment of grass and legume cover and both mat mulches and hydromulches work equally well. The decision on which mulch to use is, therefore, based on biological and economic considerations as well as the nature of the planting site. In most cases, Ringe and Graves (1987) suggest that mulching is beneficial to herbaceous cover and that hydromulches are the most feasible, especially if done in conjunction with seeding. In contrast, Collicutt (pers. comm., 1992) suggests that hydromulching should be done, if at all, after seeding to prevent the problem of the seed getting hung up in the mulch. Additional problems associated with mulching are that it may be expensive, may have a considerable requirement for labour, (depending on the method of application and the type of mulch used) and must be well anchored in areas prone to wind erosion.

6.5.5 Maintenance

Maintenance of a revegetated or reclaimed area may involve such treatments as irrigation, fertilization, weed control and protection of the site from grazing, vehicular traffic, etc.

Management may affect the dynamics of reclaimed ecosystems. Broad goals of management, therefore, are to further accelerate and direct ecosystem recovery following initially applied treatments. Surprisingly little research has been undertaken on the ecological effects of

different management practises on disturbed lands in the semi-arid west. Many potentially effective practices, such as mowing, haying, prescribed burning and herbicide applications do exist but the effectiveness in semi-arid environments is largely unresearched (Redente and DePuit 1988).

6.5.5.1 Irrigation. In many native grassland areas, irrigation of revegetated plots is not feasible, however choosing properly adapted native species should eliminate or decrease the need for irrigation.

Small tallgrass prairie plots (125 square metres) have been irrigated at the time of plant establishment using a small portable 2 hp gasoline powered pump equipped with a fire hose and spray nozzle pumping water from a truck mounted tank (Morgan, pers. comm. 1992).

6.5.5.2 Fertilization. Fertilizing plant communities influences the species composition of a stand and its successional status. The effects depend upon the season of application, the kind and form of fertilizer used, climatic conditions, soil structure and texture, the composition and condition of the plant community, and complimentary treatments such as grazing, mowing and reseeding (Romo and Lawrence 1990). The role of fertilizer application in native grassland reclamation has primarily been seen as one of promoting revegetation efforts to control erosion. The influence which it has in both the short and long term on species composition and vegetation community dynamics is not well reported in the literature. Improvement to depleted rangelands has, however, been reported through the application of high nitrogen formulation fertilizers. For example Rogler and Lorenz (1957) report an increase in western wheatgrass in pastures fertilized with 34 kg N/ha and 101 kg N/ha in the spring and fall. In an area near Manyberries, Alberta, Johnston et al. (1967) reported on differences in basal area of range species in response to varying intensities of annually applied N and P. The ecological effects of such applications have not, however, been investigated in the context of native prairie restoration.

Unless soils are particularly infertile, adding fertilizer at seeding time does not seem to increase stand densities (Ries et al. 1987b). However, adding nitrogen and phosphorus in the second growing season may ensure vigorously growing seedlings (Romo and Lawrence 1990).

One problem noted with adding fertilizer at seeding time is that it often benefits the weeds more than the native species. Most prairie perennials appear to do best on low nitrogen soils, while annuals have higher nitrogen requirements. Therefore, particularly on heavy, fertile soils that present the most weed problems, attempts are sometimes made to defertilize the soil to increase the chances of success of native plant establishment.

To defertilize soils, a mixture of sugar and sawdust may be broadcast onto a plot. The sugar enhances the growth of soil microbes which take up considerable nitrogen, thus making it unavailable for the plants (Morgan, pers. comm. 1992). The effects on soil organic matter and

overall soil quality of such a technique have not been examined in detail.

6.5.5.3 Weed Control. Weed (defined here as all invasive non-native species) control is considered by many seed suppliers and reclamationists to be the major problem encountered in attempting to establish native species (Andersen, pers. comm. 1992). Native species are initially slow growing and therefore the success of future regeneration is largely determined by the initial success in controlling the faster growing, more competitive weeds. Weeds are well adapted to compete and propagate on disturbed soil because of their good seedling vigour and growth potential (Wilson 1972). They are particularly troublesome on fertile, heavy soils.

Eradication of weeds is rarely practical, therefore the usual goal is weed control, defined as manipulation and management designed to achieve a reduction in numbers of undesirable plants (Saskatchewan Agriculture Development Fund, no date).

Weeds may be controlled manually by: pulling, digging or cutting individual plants; tillage; grazing; using natural enemies of the weed (biological control); mowing; burning; and, using chemicals.

Pulling, digging or cutting weed species is not practical for large areas but may be useful in small areas, or for spot infestations.

Deep plowing or discing is often used to rid the seedbed of weeds prior to seeding desired species. This may need to be done several times to be effective (La Fayette Home Nursery 1976). Plowing or discing should be done early in the spring but not so early that the soil will form clods. Weeds turned up by the plowing should be raked and removed, if possible, to prevent propagules from establishing under wet conditions (Salsbury Laboratories 1977). Wilson (1970) suggests that light discing may cause less moisture loss than deep plowing and achieve the same result.

Little information was located on the use of grazing as a weed control practice in native grasslands, however this technique may be limited by toxic compounds in the weeds, and where weed densities are high (Lawrence et al. 1988). A short period of grazing will control the weeds and decrease shading, increase available space, and make more water available for seeded plants (Heady 1975). Grazing as a form of weed control often involves a combination of animal species with different dietary preferences (Saskatchewan Agriculture Development Fund, no date). Sheep are sometimes used to control leafy spurge, snowberry and dandelion and goats have been used to decrease brush invasion into grasslands (Saskatchewan Agriculture Development Fund, no date; Vallentine 1971).

An ongoing study into the use of sheep as a weed control method is being conducted in the St. Mary's River basin near Cardston in a co-operative effort between several interested agencies including Alberta Agriculture, Public Lands Division of Alberta Forestry, Lands and Wildlife, the M.D. of Cardston, the Blood Indian Reserve, and others. The Public Lands Division, which is conducting the monitoring, found that

after four years of open herding of sheep, there is some decline in leafy spurge and some increase in native grass production. An added benefit is that sheep can make good weight gains eating this nutritious forage.

Biological control focuses on the use of natural enemies of a weed such as predators, parasites and pathogens. Advantages of this method of weed control are that it targets only a single species and doesn't damage the rest of the plant community or other non-target species. Disadvantages are that biological control agents are only available for selected weed species and that it is a relatively expensive form of weed control in many cases.

One biocontrol agent used in Alberta's native grasslands, the black dot spurge beetle, was introduced to southern Alberta from Hungary in 1983 (Cole 1992). The adult of this beetle feeds on the aboveground plant parts, while the larvae feed on the roots. At the original release site, populations have increased to more than 400 beetles per sq. metre and the beetle has spread over 500 m from the initial release point. There has been a noticeable decline in leafy spurge, with a corresponding increase in the amount of grasses and other native vegetation at the release site.

The black dot spurge beetle has been distributed to more than 100 sites in the province and at least three of the sites can now be harvested for further redistribution. The beetles are harvested using a sweep net to gather the approximately 500 beetles, which are then released at a location marked for monitoring purposes. The beetle appears to prefer high, dry exposed patches of leafy spurge for best establishment.

Two other biocontrol agents currently being tested for leafy spurge are the larvae of the fly *Pegomya curticomis* and the larvae of the moth *Minoa murinata*.

Other biocontrols in use or being tested, according to Cole, are the tortoise beetle to control bladder campion, stem-mining weevil and root mining moth on toadflax, and the seed-head mining weevil on Canada thistle.

Black dot spurge beetle, copper spurge beetles and tortoise beetles are currently obtainable from the Alberta Crop Protection Branch, Alberta Agriculture, the Public Lands Division of Alberta Forestry, Lands and Wildlife and the Alberta Environmental Centre, Vegreville.

Mowing for weed control is usually most effective on taller-growing species. Caution must be practised when mowing stands with bunchgrasses as these can be killed by low mowing, which takes out the crown and kills the plant. Multiple mowing is usually necessary to prevent seed set by decreasing underground food supplies. Rock (1977) mentions that the ability of rotary mowers to remove weeds and provide a mulch is an advantage, however they are considered unsuitable for rough, stony terrain as they scatter plant debris, smothering new growth (Saskatchewan Agriculture Development Fund, no date).

Prairie Restorations, Inc. (1992) recommend spring or fall mowing in prairie restoration projects in the Minnesota area to encourage flower development and keep grasses from be-

coming too dominant. They recommend mowing with a rotary or sickle type mower to a minimum height of 15 cm (6 in). Ode (1972) has suggested mowing to a 15 cm (6 in) height several times during the first growing season as the prairie species will not yet be tall enough to be harmed by this procedure. Another recommendation is to mow when weeds shade 70% of the ground or before seed heads form (Wilson 1971). Mowing may also be necessary in the second year.

Ode (1972) recommends a rotary mower as opposed to a sicklebar type mower but does not give reasons for this preference.

Once the native vegetation is established, the need for mowing should decrease as the perennial roots will spread and prevent the establishment of annual weeds. In roadside plantings in Iowa, weeds were reduced dramatically by the third year after seeding, strictly from competition from native prairie species. No mowing or spraying was required (Landers 1972).

If mowing is to be used for weed control in plantings containing forbs, the impact on these species should be considered. In Nebraska, Hesse and Salac (1972) found that intensive mowing did not adversely affect survival of three native forbs: sweet rocket (*Hesperis matronalis*), butterfly milkweed (*Asclepios tuberosa*) and gray goldenrod (*Solidago nemoralis*) studied, but did decrease the height of lateral shoots, increased the number of lateral buds and delayed and extended the blooming period.

Iverson and Wali (1987) suggested that mowing revegetating mined sites in North Dakota allowed later season species a chance to grow. Annual kochia was dominant early in the first year and acted as a cover crop protecting other emerging plants against erosion and high insolation. However these plants became so dense later in the year that they inhibited the growth of preferred species. Mowing allows desired species to advance late in the season and therefore they have a better chance to compete in subsequent seasons. Iverson and Wali concluded that mowing should be considered a management practice in revegetating mined lands.

One of the major disadvantages of mowing is that, if conditions are wet in the spring, it may be impossible to mow early to control weeds. Another problem is that too early or too frequent mowing may stimulate shorter weed growth with rapid seed head formation (Leskiw 1978). Additionally, many prairie forbs have been shown to decrease in vigour when mowed (Hesse 1973).

Burning is considered by some Northern U.S. prairie restorationists to be "the single most important tool available to establish and maintain a quality prairie" (Prairie Restorations, Inc. 1992). However this technique has obvious limitations in many restoration and reclamation projects such as restrictions on use, the large labour force required, potential for damage to adjacent vegetation types, and possible increased erosion.

Burning can be done early in the spring or late in the fall but must be done when the soil moisture is low enough to produce a fire which is hot enough to burn seeds and damage rhizomes (Bland 1970). While controlling weeds, it also stimulates the growth of native grasses, reduces

litter and competition from woody species (Leskiw 1978). Burning is often used in conjunction with mowing and grazing.

Controlled burns have been used as a management tool in dense nesting cover plantings (Ducks Unlimited, no date) but fall burns should be avoided on stands with a legume component as severe winter kill of alfalfa can result. They state that the best management scheme on native stands appears to be a combination of burn and grazing treatments.

In a tall grass prairie restoration project in Manitoba, Morgan (pers. comm. 1992) burned off existing plant cover prior to seeding, but found this to be ineffective in limiting weed growth.

Spraying with chemicals seems to be the one of the most widely used techniques for weed control in native grasslands. Herbicides can be used to alter species composition of a site by selectively harming susceptible species. The effect of the herbicide will depend on: (1) type of herbicide used; (2) amount of herbicide used; (3) season of use and phenological stage of plants; and (4) current and subsequent environmental conditions such as climate (Romo and Lawrence 1990).

The advantages of herbicide use for weed control are that they require minimum labour, cost is generally less than for mechanical control, spraying may be done on steep slopes or stony terrain where mechanized equipment cannot operate, herbicides can produce a rapid plant response over a large area, and they don't cause soil erosion, as tillage does (adapted from Romo and Lawrence 1990; Vallentine 1989b).

The disadvantages are: in native mixed grass and forb stands use of chemicals may not be possible except prior to seeding, species response differs depending on time of application, some undesirable plants cannot be controlled by herbicides while other desirable ones are eliminated by herbicide use, cost of control may be higher than the expected forage increase on some rangeland, a poor seedbed may result for subsequent seeding, careless use can damage untargeted species and contaminate the environment, and plants poisonous to livestock may be grazed more readily after chemical treatments (Romo and Lawrence 1990; Saskatchewan Agriculture Development Fund, no date; Vallentine 1989b).

Herbicides may be applied in a ground sprayer, by air, as individual stem-foliage or stem treatments (the latter two would be most suitable for small infestations or small plots). Wiper applicators are frequently used where there are large differences in height between desirable and undesirable species for example, where tree species encroach on native grass pasture (Saskatchewan Agriculture Development Fund, no date).

Prairie Restorations, Inc. (1992) recommend spraying with Roundup (glyphosphate) or Ranger herbicide to eliminate existing plants prior to tilling. Morgan (pers. comm. 1992) recommends spraying with Roundup, letting the area rest for 10 days, then seeding. Roundup is frequently used because it is a contact herbicide which only affects plants which are actively growing. It can therefore be applied early in the season

while weeds are flourishing but before the natives have been seeded.

Ducks Unlimited (no date) suggest spraying the entire field with Roundup prior or immediately after seeding for dense nesting cover plantings. They state that a light rate herbicide application is required in midsummer of the planting year. If herbicides cannot be used, the area should be mowed for weed control. Spot weed control will be required for the first two or three years of a planting.

Excellent control of crested wheatgrass and smooth brome grass has been obtained using a combined application of prescribed burning and glyphosphate (Romo, pers. comm. 1992). Burning removes litter, stimulates the growth of the introduced species, and depresses the native species, thereby increasing the height differential between the two. Using glyphosphate then hits the actively growing introduced species hardest. Grazing and mowing can also be used in conjunction with herbicide application to control exotics (Romo and Lawrence 1990).

Using clean seed and/or mulch, clean equipment, and not driving over infested areas prior to entering a reclamation site are additional suggestions to decrease weed control problems.

6.5.5.4 Miscellaneous Maintenance Recommendations. Livestock grazing should not be allowed on a revegetated native grassland until the plants are suitably established or self-sustaining. Holzworth and Lacey (1991) recommend that grazing be deferred in re-seeded pastures until the first seed crop has matured, and it may be advisable to extend the non-use period during dry years. In some cases, fencing may be desirable to prevent the use of the area by ungulates as well as livestock (Special Areas Board et al. 1992).

In drier regions, adequate moisture availability is critical for successful establishment. Techniques to conserve moisture for new plantings include snow fencing to trap snow (and therefore moisture in winter); and terracing, contour furrowing, catchment basins, pitting, mulching, topsoiling and tillage (Romo and Lawrence 1990).

6.6 MONITORING

In the context of native grassland reclamation, monitoring can be defined as an on-going, long-term effort to assess and compare the results of various reclamation and restoration methods and techniques. Certification on the other hand is an instantaneous assessment of site conditions or a spot check to compare conditions to a check list of reclamation criteria.

Monitoring is primarily the responsibility of the land owner and operator to ensure long term, site-specific data are collected which can be used to demonstrate that disturbed lands can or cannot be reclaimed by the techniques used. It is a fundamental component of any revegetation plan in order to compare pre- and post-disturbance vegetation conditions as a result of the management action. The literature, however, suggests that in many cases this aspect of vegetation management is overlooked. The importance of designing a site-specific vegetation monitoring plan has been described by Romo and Lawrence (1990) as follows:

> "Monitoring the activities and changes in the plant community enables the manager to determine if the manipulations are moving the vegetation toward the desired goal. If not, then the manager must reevaluate the alternatives and implement additional activities. In addition, this information will enable the manager to make adjustments in the current management and also to use the information for future plans."

Monitoring must be considered as a part of the vegetation management plan in order to provide information on management actions and their effects on the plant communities. It is particularly important where revegetation performance standards and criteria are used to determine reclamation success. Often such standards and criteria are based on a percentage areal cover of vegetation per unit area or a number of plants established within a particular site. The point intersect method and the Daubenmire midpoint cover class methodology have been used to monitor rangeland in this regard. Clearly, in this case, a rigorous scientific method is appropriate to allow statistical comparisons of data sets.

Where comparison of disturbed land to non-disturbed reference land is used as a basis for evaluation, a clear protocol of information collection and analysis is required to validate the monitoring effort. The validity of using native reference areas as a measure of revegetation success is quite controversial given the basic environmental differences between native reference areas and reclaimed lands (Coenenberg 1982). Nevertheless, such comparisons are likely to remain as the standard by which reclamation or restoration efforts are ultimately compared.

In summary, the role of monitoring within vegetation management plans appears to require review in terms of its objectives and methodology.

7. EXAMPLES OF NATURAL RECOVERY

7.1 BACKGROUND

Natural recovery is essentially the process of reclamation of disturbed areas by natural plant succession. Natural succession is the observed sequence of changing vegetation associations which are progressive, directional and therefore predictable (Daubenmire 1968). In deciding whether to allow natural succession to be the principle reclamation procedure the main considerations are the existing environmental conditions, time available, financial constraints, and local land use legislation (for example, the noxious weed control laws).

Few case studies are available which specifically document the natural re-establishment of native prairie. A significant constraint is the time period over which this process may occur.

Coupland (1952) described the stages of succession on abandoned land in western Canadian prairies as: (1) annual weed; (2) perennial forb; (3) annual grass and short-lived perennials; and (4) long-lived rhizomatous species. The length of each stage of succession and the time needed to produce a climax community on the Canadian prairies varies from 15 to 50 years depending on the local climatic conditions during the year of abandonment and the degree of disturbance (including both the area affected and length of time disturbance occurred) (Coupland 1952). Other studies indicate that more than 55 years may be required for natural successional processes to revegetate abandoned cropland to a condition resembling undisturbed range (Dormaar and Smoliak 1985). Romo and Lawrence (1990) suggest that "natural succession to a point where native species regain dominance is not possible within our lifespan".

Factors determining whether or not a plant community can develop, through processes of natural selection, into one resembling a predisturbance condition include: (1) the severity and frequency of disturbance; (2) the proximity of the successional vegetation to the disturbed area; (3) the reproductive potential of the successional vegetation; and, (4) the abundance of the successional vegetation surrounding the disturbance (Romo and Lawrence 1990).

The factors affecting the natural recovery process are largely dependant on climatic conditions and, hence, are expected to vary between ecoregions in Alberta. Re-establishment of an exact replica of the predisturbance plant community may be impossible because of the change in environmental conditions and/or the loss of some locally adapted plants as a result of the disturbance. During natural recovery processes introduced or strongly invasive species may preclude the establishment of desired native species.

The effects of disturbance on species composition are variable depending on the vegetation history of the area and the life history of the dominant vegetation and those introduced or invasive species which may be present (Armesto and Pickett 1985).

7.2 SURFACE DISTURBANCE CASE STUDIES

Surface disturbances which may occur within native grasslands have been previously identified (Section 5.0). They are essentially activities which require little or no physical disturbance of the soil surface. There are few case studies which overview instances of natural revegetation for surface disturbances. No Alberta case study was found.

7.2.1 Vegetation Responses to Spring Burning in Western South Dakota

7.2.1.1 Background and Disturbance Type. Responses of a mixed grass prairie community to spring burning in 1976 were monitored by Gartner et al. (1984) for two growing seasons. The study area was located on a nearly level bench in the southwest corner of Wind Cave National Park (South Dakota). Annual average precipitation is less than 425 mm, 78% of which normally occurs between early April and late September. Soils were deep, dark-reddish coloured silt loams with calcareous, silty clay subsoils. Slopes ranged from 2% to 6%, increasing to about 25% at the northern edge of the study area where the grassland gives way to a shrub community.

7.2.1.2 Objectives. The burn was instigated to evaluate the ability of a burned area to revegetate through natural recovery processes.

7.2.1.3 Approach and Methods. In the spring of 1976 about 6 to 8 ha of mixed prairie grassland were burned under conditions which included a strip-headfire and a flank fire. Small areas of non-burned lands were protected as controls in both burned and non-burned land. Vegetation yields were sampled in August 1976 and July 1977 on the burn and adjacent unburned areas. The current years growth was clipped and vegetation samples separated into nine species groups (western wheatgrass, needle and thread, green needlegrass, bluegrasses, shortgrasses, other grasses and sedges, forbs, and shrubs). Samples were dried and weighed.

The heights of various species were randomly sampled at different times of the year throughout the burned area. In mid-July the density of the species were estimated and stem counts made.

7.2.1.4 Results and Discussion. Yields of nearly all vegetation components were considerably lower in 1977 than in 1976. Total vegetation yields on the burned areas in both 1976 and 1977 were significantly lower than those in the unburned area. Several factors, in addition to precipitation deficits, could have contributed to suppressed yields on the burned area. For instance, the removal of natural mulch, in the form of litter, results in exposure of the soil and plant roots to winter cold and unfavourable soil moisture conditions. These conditions, in addition to the physical burning process, may result in lowered plant yields.

Grazing of natural regrowth vegetation on burned lands may result in increased stress to the plants. The degree of stress is compounded when

soil moisture is deficient. Accordingly, even when lands are left to revegetate by natural succession it is important to control livestock and wildlife movements on reclaiming land.

Under some conditions, however, burning effectively increases yields of some species on native ranges, particularly western wheatgrass and shortgrasses, and decreases yields of exotic species. A more detailed review of the role of fire in grassland ecology and its potential use in reclamation is provided in Appendix I.

7.2.2 Recovery of Vegetative Cover and Soil Organic Matter During Natural Revegetation of Abandoned Farmland in a Semiarid Climate - Shortgrass Prairie, Southeastern Alberta

7.2.2.1 Background and Disturbance Type. A study by Dormaar and Smoliak (1985) evaluated the vegetation cover and the soil organic matter condition for three formerly cropped sites near Mannyberries, southern Alberta. The sites are located within the dry mixed grass ecoregion. Orthic Brown Chernozemic soils predominate under the semi-arid grassland conditions. A site referred to as 1925 had been cultivated for 15 years and abandoned in 1925. Site 1927 had been cultivated for 10 years and abandoned in 1927. Site 1950 had been cultivated intermittently for 30 years and was abandoned in 1950. The adjoining native range was used as a control to evaluate the natural succession of vegetation on abandoned farm lands, and to study the natural development of the soil.

7.2.2.2 Approach and Methods. Ten soil cores, sampled to 60 cm depth, were obtained randomly from each site. Soils were characterized and tested for root weights, organic matter, nitrogen, pH and water-stable aggregates. Vegetation ground cover and species composition of the study sites were determined and compared to the communities occurring on the adjacent native grassland.

7.2.2.3 Results and Discussion. Total organic matter and total nitrogen were found to be higher on the naturally revegetated site 1925 as compared to site 1950. However, although the 1950 site had a lower organic matter content, more of the organic matter was extractable, possibly due to varying species compositions between sites.

Species diversity was greater on the native grassland than on the disturbed land. Blue grama grass dominated the revegetated sites for all years studied. Needle and thread was the dominant vegetation cover for native rangelands, with secondary proportions of blue grama grass and June grass. The native rangelands had a higher proportion of forbs and shrubs than did the revegetated land. Total species composition was more variable for native rangeland than for revegetated land. The total vegetative ground cover was approximately equal for both naturally revegetated lands and undisturbed native rangelands, but below ground biomass was consistently greater on the native range.

Dormaar and Smoliak (1985) concluded that the higher amount of blue grama grass on the abandoned sites indicated that this species is more

plentiful during earlier stages of succession than in the climax communities. Furthermore, it appeared that more than 55 years is required for the natural revegetation of abandoned cropland to approach species composition and abundance of the undisturbed range.

7.3 SOIL DISTURBANCE CASE STUDIES

Soil disturbances which may occur within native grasslands have been previously identified (Section 5.0). They are essentially activities which require some physical movement of, or modifications to, the soil or terrain.

7.3.1 Problems of Native Prairie Reconstruction Following Pipeline Construction Through Solonetzic Native Rangeland on Mixed Grass Prairie in Southern Alberta

7.3.1.1 Background and Disturbance Type. The study was carried out by Dr. Naeth - Departments of Soil Science and Plant Science, University of Alberta (Naeth 1986; Naeth et al. 1987; Naeth et al. 1988)

The study area was located 10 km east of Princess, in the dry mixed grass ecoregion of Alberta. The area is characterized by a semi-arid moisture regime; slopes of less than 2%; till, glaciofluvial and glaciolacustrine surficial sediments; Brown Solod and Brown Solodized Solonetz soil profiles with eroded "blowout" pits where most of the topsoil has been lost to wind erosion. The native vegetation cover consists of a blue grama-speargrass-wheatgrass community.

Five adjacent natural gas pipelines on a series of rights-of-way were studied at four sites. The pipelines had been installed on native range lands during 1957, 1963, 1968, 1972 and 1981. Pipeline diameters were 86 cm, 86 cm, 91 cm, 107 cm and 107 cm, respectively. Construction procedures were similar for all pipelines, with grading having taken place prior to pipe installation and topsoil salvage restricted to the trench line only. Trenches, 30 to 60 cm larger than pipe diameters, were completed using a ditcher, and then backfilled. At least 80 cm of soil was reclaimed over the 1972 and 1981 pipelines and at least 50 cm of soil was reclaimed over the 1957 and 1963 pipelines. The 1957 and 1963 lines were left to revegetate naturally.

7.3.1.2 Objectives. Ultimately the land was to be utilized for native range comparable to that existing in the area prior to disturbance. Topsoil replacement over the trench spoil was the only active reclamation activity undertaken. Vegetation was left to re-establish by natural succession.

7.3.1.3 Approach and Methods. Four disturbed sites along the pipelines were selected for study. The goal of the project was to assess the effects of pipeline installation on Solonetzic soils and mixed prairie grasslands, evaluating the time-based response of selected ecosystem parameters to disturbance.

Each study site was 100 m by 135 m, spanning the right-of-way with undisturbed native prairie (control) occurring on either site. Each study site was divided into 17 transects, representing different ages of pipeline right-of-way and

different disturbance types (trenching, pipelaying, stockpile and work areas).

Three to five soil cores were collected for each transect and samples analyzed to a total depth of 60+ cm. Lab testing was undertaken to determine organic matter content, texture, soil moisture retention, pH, electrical conductivity, ion composition, and bulk density.

Vegetation communities were assessed to determine the species composition as well as the frequency and ground cover values for two seasons.

7.3.1.4 Results and Discussion. Pipeline construction was found to have significantly altered the physical and chemical properties of the immediate edaphic environment; and, many of the changes were persistent over time. However, with respect to natural recovery of the site, these changes did not seem detrimental to plant growth.

The mixing of soil horizons during trenching resulted in an increased surface clay content on the disturbed sites. Further, compaction by vehicles and machinery, combined with the higher proportion of clays at the surface, resulted in an increased surface bulk density. However, the bulk density of the subsoil (Bn) horizon was actually reduced by the disturbance, thereby increasing the potential for infiltration of soil moisture and penetration of plant roots.

Changes in bulk density of the soil persisted over time and, although surface bulk density declined over the trench within ten years, there was no further decline towards predisturbed conditions. Soil moisture status was only affected for a short period of time after development, with a rapid movement towards predisturbed conditions within 25 years.

The mixing of soil horizons during trenching resulted in a number of changes to the soil chemistry. Organic matter was found to be significantly lower in disturbed transects as compared to adjacent control sites. The undisturbed control had 2.5 times higher organic carbon levels than the 1957 disturbed trench site, and 4 times higher levels than the 1968 site. There is, however, an indication that the levels of organic carbon are improving with time. Other notable changes to soil chemistry included an increased uniformity of parameters, such as pH, ion activity and various elements, over depth. Again, this trend is attributed to the mixing of various soil horizons. Sodium adsorption ratios (SAR) increased with depth for all transects. The older rights-of-way usually had higher SAR values than the undisturbed prairie to a depth of 15 cm.

Botanical composition of the right-of-way was severely altered by pipeline construction and changes in vegetation due to pipeline construction were compounded by the grazing regime imposed on the system. Ground cover and species composition of the 1957 right-of-way was most similar to that of the undisturbed prairie, indicating a return toward predisturbance vegetation conditions. This return was most rapid for transects on the right-of-way but outside the direct influence of the trench. Unfortunately little quantitative information is presented on comparisons of vegetation composition between study sites.

The grazing regime of the site influenced species composition during early revegetation. Late season grazing favoured the re-establishment of introduced species or dominant pioneer species. Early season grazing, while reducing the potential for dominance by introduced species or by dominant pioneer species, did result in a higher proportion of bare ground cover and increased the potential for erosion.

Some erosion was evident along the pipeline rights-of-way. Bare ground existing during the initial stages of revegetation resulted in increased wind erosion but subsequent rapid revegetation by pioneer species appeared to reduce this problem. Berm construction along the rights-of-way had impeded drainage during spring-melt, causing erosion problems.

8. EXAMPLES OF ENHANCED RECOVERY

Enhanced recovery of disturbed areas involves human intervention, in the form of reclamation or restoration efforts following the disturbance. The goal of enhanced recovery of disturbed native grasslands is to create an appropriate soil substrate, suitable for sustaining the selected vegetation and producing a vegetation cover, incorporating native plant species.

8.1 SURFACE DISTURBANCE CASE STUDIES

Surface disturbances which may occur within native grasslands have been previously identified in section 5.0 and include, for example, grazing, burning and periodic vehicle or pedestrian traffic which results in vegetation impacts. Surface disturbances are essentially activities which require little or no physical disturbance of the soil surface. There are few case studies which document the reclamation of surface disturbances only.

A unique approach to prairie grassland restoration involves limiting surface disturbance to the sod layer by removing the grassland sod from areas which will be disturbed and transporting them to areas to be reclaimed. An example of this approach is discussed in the following section.

8.1.1 Urban Community Restoration of Rough Fescue Grassland, Calgary, Alberta

8.1.1.1 Background and Disturbance Type. Edgemont is a community in northwest Calgary which extends along the edge of Nose Hill, an outlier of the Rocky Mountain foothills and is located within the fescue grass ecoregion. Approximately 40% of the community is dedicated to urban greenspace, much of it is unbroken native fescue grassland and shrubland, generally contiguous with Nose Hill Park. During the process of residential and road construction, much of the native prairie in the green zone was lost, due to both surficial and soil disturbances.

As part of the overall community landscape plan, the Edgemont Community Association proposed to use native prairie species for revegetation of about 1.6 ha of sloping land located adjacent to the school and community yards. The potential exists for additional areas to be similarly revegetated, depending on the findings of the pilot project. Revegetation studies were undertaken by Dr. Revel, Department of Environmental Design, University of Calgary and a resident of the Edgemont community.

8.1.1.2 Objectives. The reclamation objectives were to revegetate the disturbed slope area with native grasses and shrubs typical of the native fescue grassland in the adjacent Nose Hill Park. The project was undertaken for educational, aesthetic, wildlife and habitat restoration purposes. The proposed end land use would be an undesignated natural area for the community, as well as serving to extend the native grassland reserve of Nose Hill Park.

8.1.1.3 Approach and Methods. The disturbed area was characterized by a rough fescue grassland, interspersed with patchy trembling aspen

communities on more moist north-facing slopes and within gullies and depressions. Because of difficulties in obtaining rough fescue seed, the transfer of rough fescue sods from those areas designated for permanent development within the study area was suggested as a means of revegetating surface disturbances. It was thought that this process would allow for the purity of the rough fescue gene pool to be maintained, and further, that the individual species provenances would remain unaltered. If restoration by this method was successful, the project would contribute to the preservation of the rapidly diminishing rough fescue grasslands in and around the Calgary area. Furthermore, the project could become a model for other such revegetation programs associated with urban and other developments in the rough fescue grassland ecosystem.

Two major problems were evident. First, it was necessary to establish whether there was a sufficient area of accessible native prairie and shrubland, marked for future development, which could provide the necessary sod. Second, it was necessary to determine a successful and efficient method for transplanting the volume of sod needed for the revegetation program.

An inventory of impending development sites resolved the first problem, as there was ample rough fescue grassland area designated for development within the Edgemont area. The second problem required some experimentation to develop adequate sod transplant techniques. Accordingly a number of study sites were established whereby different sod cutting and moving methods were tried. These included using a standard sod cutter, set to cut a sod 5 cm thick; and, using scrapers that cut sod blocks in thicknesses from 15 cm to 36 cm.

Sods were transplanted into a test area watered and left to establish over a period of several seasons. The success of the transplants was evaluated on the basis of species recovery and the naturalness of the revegetated rough fescue grassland community. Trembling aspen seedlings were also established within the test area. A larger scale program was undertaken to cut sod and revegetate an area adjacent to the school and community centre. Cut sods were introduced on the site, anchored to prevent slumping, and watered regularly. Some trembling aspen seedlings and spruce trees were also planted at the site. Volunteers within the community were involved with the experimental stages of the program and completed the initial site restoration work.

8.1.1.4 Results and Discussion. Although complete results will not be available for at least one growing season (1993), some preliminary results are available from pilot studies. The rough fescue sodding techniques appeared successful in preserving the general species composition of the grassland community. A number of wildflowers and forbs were noted among the grasses suggesting survival of much of the natural vegetation community. In the pilot study few weedy species were noted as becoming dominant in the revegetated area indicating the vegetation community remained relatively stable following the transplant. However, where revegetation was undertaken

adjacent to the school and community centre there is some concern that weedy species may dominate in the spaces between the sods as a result of invasion from the non-native grasslands.

A concern with respect to sodding is the maintenance of transplanted areas where watering is not available, particularly where sods are placed over a large area and initial watering is not feasible. No costs were available on the project to date.

8.1.1.5 Monitoring. Monitoring is ongoing for both the pilot project and the revegetation project areas. The species composition, vegetation community dynamics, and the proportion of weedy species present in the revegetated areas are of interest in determining the long-term success of this sodding approach to reclaiming or preserving areas of native fescue grasslands.

8.2 SOIL DISTURBANCE CASE STUDIES

A variety of soil disturbance within native grasslands have been the subject of reclamation efforts within Alberta and throughout the prairie provinces. Unfortunately few of these examples have been reported in the scientific literature and available information is rather anecdotal in nature. As a result, comparisons of methods, techniques and practical details which document successful and unsuccessful restoration efforts are typically not available.

The following case studies provide examples of the types of reclamation and restoration projects which are currently being undertaken.

8.2.1 Reclamation of Disturbed Native Aspen Parkland/Rough Fescue Grassland, Rumsey, Alberta

8.2.1.1 Background and Disturbance Type. Rumsey is located within the aspen parkland ecoregion and typifies the native vegetation conditions associated with this ecoregion. Oil and gas development (wellsite development, pipeline installation and road construction) has resulted in a number of disturbed sites, some of which are currently being reclaimed using various revegetation techniques.

The attempt to use native seed mixtures was initiated in 1983 under the guidance of Alberta Forestry, Lands and Wildlife, Public Lands Division. This case study and the findings presented herein are based on correspondences with personnel in Alberta Forestry, Lands and Wildlife (Barry Cole, David Lloyd and Morris Seiferling, pers. comm. 1992), and from data available from excerpts of a study on the encroachment of native species onto reclaimed sites within the Rumsey Block (Integrated Environments 1991).

8.2.1.2 Objectives. The objectives of the Public Lands Division were to re-establish native species on selected test sites within the Rumsey block comparable to the pre-disturbance conditions in terms of species composition and abundance.

8.2.1.3 Approach and Methods. Several methods were utilized to revegetate disturbed areas with native species. The method chosen for a specific

site was largely dependent on the nature and degree of disturbance. It should be noted that the process of determining which methodologies are considered the most effective is ongoing and modifications to site preparation practices, topsoil conditioning, seeding practices and seed mixture composition may be expected to change as further monitoring information becomes available. The methods initially used are summarized as follows:

Method 1: On narrow linear sites (< 4.5 m wide) and where erosion is not a significant problem, introduced topsoil was spread over the disturbed area and native grasses allowed to revegetate the site. Three or more years were estimated for full revegetation to occur although grazing may significantly slow the process. On-going weed control was implemented.

Method 2: On larger sites, introduced topsoil was spread over the site followed by a mulch containing native seeds. The seed mulch was collected from a suitable native grassland area located near the disturbance site. Mowing was done when seeds were mature but before they would shatter. The mulch required at least 33 kg of seed per ha (30 pounds/acre) primarily in the attempt to account for the low germination rate of rough fescue. Grazing was excluded from the site for at least three years after seeding, and for an additional two years if the topsoil was shallow.

Method 3: Topsoil was spread over the disturbed site and a mixture of native seed most closely resembling the pre-disturbance native vegetation community was sown directly. One of two seed mixes were used and are described here as a percentage by species weight: Seed Mix A - 10% Common Perennial or Annual Ryegrass, 25% Durar Aurora Hard Fescue, 30% Walsh Western Wheatgrass, 15% Elbee Northern Wheatgrass, 10% Reubens Canada Bluegrass, and 10% Revenue Slender Wheatgrass; and, Seed Mix B - 10% Common Perennial or Annual Ryegrass, 35% Nakiska Sheeps Fescue, 25% Sodar Streambank Wheatgrass, 15% Revenue Slender Wheatgrass, and 15% Reubens Canada Bluegrass. Seed Mix A is the preferred mix but the provision of a second mix option recognizes frequent difficulty encountered in obtaining specific seed.

All seeding was done at a rate of 22 kg/ha (20 lb/acre) for both mixes. The seeding method was by broadcasting and harrowing or by drill seeding at shallow depths. Areas which were subject to grazing were not fertilized to prevent overgrazing of lush vegetation growth. Fertilizer application on areas excluded from grazing consisted of up to 38.5 kg/ha (35 pounds/acre) of nitrogen. Grazing was excluded for at least 2 years, or longer if suitable levels of vegetation were not reached by that time. Weed control was conducted to enhance grass establishment.

8.2.1.4 Results and Discussion. Integrated Environments (1991) conducted vegetation inventories at six sites within the Rumsey block which had been subjected to the reclamation efforts described previously. The study was designed to determine whether the vegetative cover within the disturbed areas is approximating that of the adjacent native prairie. A paired transect sampling technique was used to compare species composi-

tion within plots located in native and disturbed areas.

Monitoring studies in 1991 determined that the native species in lands adjacent to the four actively reclaimed wellsites were unable to compete with some species introduced into the area in the seed mixes used for revegetation. Accordingly, the reclaimed sites were almost completely dominated by non-native species and were not characterized by a species composition similar to that of the adjacent native prairie grassland. Furthermore, there was obvious encroachment of the introduced grasses into the surrounding native grassland. Efforts to control grazing of the wellsites had no apparent effect in the promotion of native versus seeded plant species within the disturbed area. The species considered most aggressive in this reclamation scenario included awnless brome, slender wheatgrass, crested wheatgrass, northern wheatgrass, quack grass, Canada bluegrass, Kentucky bluegrass, yellow sweet clover, Timothy, red fescue and Canada thistle. Rough fescue was the least successful of the seed-mixture species in becoming established.

The fifth wellsite, which was not seeded during reclamation, was also dominated by aggressive colonizers, most notably awnless brome and yellow sweet clover. However, a number of native species were successful in becoming established at this site, including milk vetch, pasture sagewort and needle grass.

The native prairie in the region had a considerably different species composition than that of the reclaimed areas. The vegetation generally typified that of a rough fescue grassland, with the most common species including: rough fescue, needle grass, sedges, June grass, pussytoes, pasture sagewort and cut-leaved anemone.

Based on the results collected in 1991, the seed mixtures for reclamation in the Rumsey Block have been revised in an effort to improve the seeding success and the compatibility of the seeded area to the adjacent native grassland areas.

In general the reclaimed linear disturbances were characterized by more successful reclamation than the wellsites. These areas had a significantly higher similarity to the adjacent native grassland than did the wellsites. This was especially evident along two sections where no grading or reseeding had taken place. The success of natural revegetation of native species on these sites was thought to be partly due to the proximity of native grasses adjacent to either site of the linear disturbance area. In addition, these areas were less impacted by sod disturbance than were other sites.

The vegetation survey also indicated that mixtures containing 10% to 20% of native wheatgrasses and yellow sweet clover resulted in better establishment of native species on linear disturbances. However, some measures are required to control the tendency for the sweet clover to invade the adjacent native prairie. Grazing management could be implemented to reduce the potential for overgrazing which leaves areas exposed and prone to invasion by species such as sweet clover. Further assessment also suggested that a mixture of native species should include no more than 40% to 50% rhizomatous grasses, thereby favouring the dominance of native grasses.

Barry Cole (pers. comm. 1992) indicated that the preferred seed mix used in the Rumsey Block has again been re-evaluated and revised in order to better approximate the species composition of the native grassland. The currently recommended native seed mixture for the area (by volume) is: 25% green needle grass, 25% June grass, 20% sheep fescue, and either 10% of two wheatgrasses or 20% of one wheatgrass of the following - western wheatgrass, slender wheatgrass and northern wheatgrass. This revised mix is recommended because both green needle grass and June grass are found in the adjacent areas and will normally be found in greater quantities where the range is under stress. Once these species are established there is better chance for the establishment of rough fescue.

Both western and northern wheatgrass are of a spreading nature due to their rhizomes, while the other species in the above mix are bunch grasses. The majority of native species in the adjacent prairie are of the bunch grass type, except for rough fescue, which is rhizomatous. It is the intent that the seed mixture be largely of the bunch grass type, so that rough fescue may become established in between the tussocks. For this reason the preference in seed mixtures is that either slender wheatgrass be used alone or with one of the other wheatgrasses. The use of two sod-forming wheatgrasses is not considered desirable. Other sod-forming species, such as brome grass, Kentucky blue grass, Canada blue grass or creeping red fescue were not included because they often inhibit establishment of rough fescue.

The establishment of weeds within disturbed areas can be expected. However, the Rumsey area is considered relatively "clean" of weedy species and, hence, the invasion of numerous weedy species such as dandelions and narrow-leaved hawks beard is not considered a major problem with respect to revegetation planning. However, the establishment of species such as Canada thistle or butter-and-eggs toadflax would require some remedial action.

As of 1992, the preferred method of seeding is with a pack drill. If unavailable, any seed drill along with a separate packer can be used. Fertilizer should be applied at the time of seeding, with the recommended fertilizer mix based on the results of specific soil sample analysis.

At present there are no results or evaluations available to document the successes or failures of the revised methods and seed mixes for this study.

8.2.1.5 Monitoring. The Rumsey Block grassland reclamation project will continue to be re-evaluated, and is the subject of considerable monitoring activities to ensure the best reclamation efforts are implemented, evaluated and, where necessary, revised. This project is one of the longest running case studies found for native grasslands in Alberta and should continue to provide a basis of comparison for revegetation programs in the aspen parkland and fescue grass ecoregions. Unfortunately little information is available on reclaimed soil conditions which would provide a valuable link between the role of soil

conditioning in the revegetation of disturbed sites by native species. Detailed systematic information on community dynamics and species interaction collected over time could also have contributed to the knowledge of prairie restoration efforts.

8.2.2 Use of Native Grasses and Forbs in Revegetation of the Shortgrass Plains Region in Southeastern Montana

8.2.2.1 Background and Disturbance Type. DePuit and Coenenberg (1979) of the Montana State University, Agricultural Experiment Station, Bozeman, Montana, tested seed mixes of improved native plant species at the Colstrip and Decker Coal Mines in southeastern Montana.

The study area is characterized by a semi-arid continental climate with about 400 mm precipitation annually. The topsoil is typically sandy and supports a variety of xerophytic and mesophytic grasses and forbs. Reclamation using various native grassland species has been underway since 1973, with modifications to species mixes being implemented as necessary to maximize the success of the program.

8.2.2.2 Objectives. The objectives of the research were to test the ability of improved native seed mixes to successfully reclaim highly disturbed mine sites to a level of vegetation cover consistent with the adjacent prairie.

8.2.2.3 Approach and Methods. Tests were carried out on well prepared sites which had been ripped, topsoiled, disc or chisel plowed, cultipacked and harrowed. Reclamation at the Colstrip site consisted of topsoiling and chisel plowing. Topsoil of 15 cm or 38 cm depths have been replaced on the site. The seed-beds were chisel plowed to a 30 cm depth and fertilized (16-20-0) with 39.6 kg N and 16.3 kg P per hectare. The native species used are outlined in Table 15. The Decker site was prepared by topsoiling and disc plowing prior to seeding. Complete fertilizer was applied but the rate and timing is unclear (Sims et al. 1984).

8.2.2.4 Results and Discussion. On the Colstrip mine site, increasing the number of species in the seed mix increased the diversity without decreasing plant productivity.

The study determined that wheat grasses were the most successful and productive in revegetating the disturbed sites. Other species which performed well during reclamation include green needle grass, blue grama grass, side-oats grama, brome grasses and big bluestem. Sand grass is recommended for dry, sandy soils and reed canary grass is recommended for wetter areas.

8.2.3 Over-stripping Topsoil During Pipeline Construction on Native Rangelands in Southeastern Alberta

8.2.3.1 Background and Disturbance Type. A 400 m segment of the 24 km Nova Corporation Youngstown Lateral Loop pipeline was chosen as a trial site for an evaluation of the effects of different topsoil stripping depths on soil quality and,

Table 15. Native Species Seed Mixture Establishment List - Colstrip, Montana (1977)

SCIENTIFIC NAME	COMMON NAME
Agropyron dasystachyum	Thickspike wheatgrass
Agropyron riparium	Streambank wheatgrass
Agropyron smithii	Western wheatgrass
Bouteloua curtipendula	Sideoats grama
Calamovilfa longifolia	Prairie Sandreed
Agropyron inerme	Beardless wheatgrass
Agropyron trachycaulum	Slender wheatgrass
Oryzopsis hymenoides	Indian ricegrass
Poa compressa	Canada bluegrass
Andropogon hallii	Sand bluestem
Schizachyrium scoparium	Little bluestem
Sporobolus cryptandrus	Sand dropseed
Stipa viridula	Green needlegrass
Artemisia ludoviciana	Cudweed sagewort
Artemisia cana	Silver sagebrush
Atriplex canescens	Fourwing saltbush
Chrysothammus nauseosus	Rubber rabbitbrush
Rosa woodsii	Woods rose
Amorpha canescens	Lead plant
Helianthus annuus	Annual sunflower
Balsamorrhiza sagittata	Arrowleaf balsamroot
Echinacea angustifolia	Black samson
Helianthus rigidus	Stiff sunflower
Thermopsis montana	Montana thermopsis
Linum lewisii	Lewis flax
Petalostemum purpureum	Purple prairie clover
Ratibida columnifera	Prairie coneflower
Achillea millefolium	Western yarrow

Source: Sims et al. 1984

ultimately on revegetation and native range productivity. The details of the study are provided in Finlayson and Landsberg (1992).

The study area is located within the northern extent of the dry mixed grass prairie ecoregion of Alberta. Soil development consists of a mosaic of thin Orthic Brown Chernozems and Brown Solodized Solonetz profiles. The region is characterized by limited precipitation and is located within agro-climatic area 2A. Native vegetation communities consist of mixed grasses and forbs, including June grass, alkali grass, needle and thread, snowberry and fringed sage.

Orthic Brown Chernozems within the study area generally consist of sandy loam profiles, with little to no structural development, occurring over calcareous, coarse loamy, stone-free glaciofluvial parent materials. Topsoils average 10 cm in depth, overlying Bm and BC horizons. In some profiles a hardpan layer, possibly a remnant buried solonetzic soil horizon was present above the parent material. The parent material (Ck) horizon is strongly calcareous, generally occurring at about 75 cm within the soil profiles.

Brown Solodized Solonetz soils occur in several small, distinct patches within the study area. The soil profiles have a fine loamy texture and are characterized by a thin (5 to 6 cm) topsoil (Ah) horizon overlying a strongly developed, hard, columnar solonetzic (Bnt) horizon. A thin eluvial band (1 cm) occurs between the topsoil and subsoil. The moderately fine-textured, saline and sodic glacial till parent material forms a calcareous (Csak) horizon, occurring as shallow as 10 cm from the surface in some profiles.

Solonetzic Brown Chernozemic soil profiles occur within the soil association for the study area, reflecting somewhat of an intergrade condition between the Orthic Brown Chernozem and the Brown Solodized Solonetz soils. The profiles are characterized by a stronger, columnar subsoil structure than is present in the Orthic Brown Chernozem profiles. There may be significant intergrading of the subsoil (Bm) horizon into a weakly solonetzic (Bnj) horizon, particularly where soils are less coarse. The calcareous parent materials occur at a shallower depth in the profile and some sodic till parent materials may occur at depth.

Typically soils in this area are characterized as difficult to revegetate after pipeline construction due to low precipitation rates, very thin topsoil depths and the potential for wind erosion.

8.2.3.2 Objectives. The objective of the project was to determine if four different topsoil stripping depths caused any long-term difference in soil quality or range productivity on pipeline rights-of-way in southeastern Alberta.

8.2.3.3 Approach and Methods. The four topsoil stripping methods included no stripping, 10 cm topsoil stripping, 20 cm topsoil and subsoil stripping, and 30 cm topsoil and subsoil stripping. The 10 cm stripping program corresponded to the average depth of topsoil along the R-O-W. The 20 cm and 30 cm stripping programs corresponded to a 200% and 300% dilution of topsoil

with subsoil, respectively. Each treatment area is approximately 70 m long and has an adjacent off R-O-W control area, 20 m wide consisting of undisturbed native prairie grassland.

Normal pipeline construction procedures were followed as closely as possible during construction of the treatment plots. Pipeline construction was completed during the early winter period. Post construction soil sampling was undertaken during the spring of 1990 and the spring and fall of 1991.

Soil sampling was facilitated using a Shelby tube mounted on a power auger, with samples extracted from the Ah (0 to 10 cm), Bm/Bnt/Bnjt (10 to 30 cm), BC (30 to 60 cm) and Ck (60 to 100 cm) horizons. The samples were analyzed for pH, EC, SAR, and saturation percentage. The percentage organic carbon was also determined for topsoil (Ah) samples. Soil strength for each treatment site was measured along the trench line and within the control areas, one year after construction using a soil penetrometer.

The sites were revegetated with a native seed mix following completion of final clean-up in 1989. However, limited quantitative measurements of vegetation growth could be made the following year and are not reported in the monitoring report.

8.2.3.4 Results and Discussion. A discussion of the results is presented for each soil parameter investigated for each of the treatments (different topsoil stripping depths).

Soil pH values were generally found to be higher over the trench line than the control site with the greatest increase in pH occurring after construction in the 0 to 10 and 10 to 30 cm depth increments in the 0 cm treatment. Trench pH remained significantly higher than both preconstruction and control levels to 30 cm depths two years after construction. In the 10 cm treatment, two years after construction, pH levels had increased significantly in the 0 to 10 and 10 to 30 cm depth increments compared to the control. In the 20 cm treatment, the 0 to 10 cm depth increment showed trench pH to be close to control levels after two years of construction. In the 60 to 100 cm depth increment trench pH was significantly lower than control levels. The 30 cm treatment showed pH levels remained significantly higher two years after construction in the 0 to 10 and 10 to 30 cm depths but decreased in the 30 to 60 and 60 to 100 cm depth increments.

Electrical conductivity (EC) values remained significantly different than pre-construction levels in the 0, 10 and 30 cm treatments. In the 0 cm treatment, trench EC levels were significantly lower two years after construction compared to levels one year after construction in the 0 to 10 cm depth increment but remained significantly higher than pre-construction and control levels. The EC of the 10 to 30 cm depth increment remained significantly higher than pre-construction and control levels two years after construction. The 10 cm treatment preserved pre-construction trench EC levels to the greatest degree near the surface (0 - 10 cm) However, EC levels remained significantly higher at the 10 to 30 cm and the 30 to 60 cm depths for two years after construction. In the 20 cm treatment a significant

decrease in trench EC occurred between years one and two, in the 10 to 30 cm and the 30 to 60 cm depth increments. Comparing trench to control EC two years after construction, trench EC was significantly higher than control EC only in the 10 to 30 cm increment. The 30 cm treatment showed trench EC levels two years after construction remained significantly higher than pre-construction levels only in the 0 to 10 cm depth increment. Broadly similar values were reported for SAR values and saturation percentage.

Two years after construction, trench organic matter percentage remained significantly lower than pre-construction levels in the 0, 20 and 30 cm treatments. Only the 10 cm treatment appeared to have adequately preserved organic matter percentage in the 0 to 10 cm treatment. There were no significant differences between organic matter levels one and two years after construction.

The conclusions from this study suggested that two years after construction, the 20 cm stripping treatment appears to best preserve pre-construction conditions on the trench. A general trend is indicated in the return to pre-construction levels for trench soil parameters, particularly EC and SAR values, however, pH values are inconsistent and require further monitoring. Reduced soil strength on the trench compared to the controls remained two years after construction. General observations on revegetation throughout the growing season revealed little difference between species composition on any of the various treatment sites; however, the non-stripped area (0 cm treatment) was generally more sparsely vegetated and weedy compared to controls.

8.2.3.5 Monitoring. This project is ongoing and further reports are anticipated.

8.2.4 Diversity and Seasonal Variety in Reclaimed Native Grasslands in North Dakota

8.2.4.1 Background and Disturbance Type. Basin Electric Power Cooperative and the North Dakota Public Service Commission undertook reclamation of the Glenharold Mine in North Dakota. This case study is summarized on the basis of reporting by Nilson and Hirsch (1989).

The study area is characterized by native mixed prairie, dominated by needle-and-thread grass, blue grama, prairie sand reed, little bluestem, sand blue stem and sedges. An area of 216 ha had been disturbed by surface coal mining operations and reclamation subsequently undertaken between 1981 and 1983. Mining entailed first removing the topsoil and selectively stripping the sandy clay and clay subsoils to a depth of 7.5 m (25 ft) in deposits of brown glacial till. Adjacent lands were stripped of topsoil but the subsoil was left in place.

8.2.4.2 Approach and Methods. Reclamation of the mine site entailed grading and contouring the spoil and applying the subsoil and topsoil layers evenly in their correct orders. Adjacent lands were graded and the topsoil replaced evenly over the subsoil. The area was divided into 19 vegeta-

tion areas according to the reseeding dates and methods used, for soil replacement as well as revegetation.

Sites revegetated in 1981 were seeded using the same mixture, including combinations of western wheatgrass, intermediate wheatgrass, big bluestem, sand bluestem, little bluestem, side-oats grama, blue grama, prairie sandreed, switchgrass, sand dropseed, green needlegrass and sweetclover.

In 1982, alfalfa replaced sweet clover in the revegetation mixes and in 1983 intermediate wheatgrass was replaced by slender wheatgrass. Attempts were made to establish a seed mix with the best blend of warm and cool season species.

All sites except one were mowed on a regular basis in order to prevent excessive litter accumulation and in order to reduce the competitive advantage of intermediate wheatgrass. The timing of this activity was deemed critical.

The herbicide, "Roundup", was used to suppress cool-season weeds or non-desirable species. As it affects those species which are actively growing, its application early in the season, prior to the emergence of warm season species, is important. Warm season species, particularly intermediate wheat grass, were found to respond dramatically after several growing seasons with reduced competition from cool season species.

The types of plant production and the cover values were established from 1982 through 1988. Three sites were selected for long-term monitoring to establish the broad species base for reclamation purposes. Differences in revegetation success, based on different seeding dates (May or June) were evaluated. The effect of using native hay mulch from nearby rangelands, and the effect of non-selective herbicide treatments were also tested.

8.2.4.3 Results and Discussion. When the revegetation program is designed to establish seasonally balanced grasslands then the planting date is an important parameter in reclamation. Planting too early favours cool season species while planting too late favours warm season species, to the exclusion of other season species, respectively. Droughty conditions may considerably alter the typical conditions expected.

The use of native prairie hay as a mulch and a complimentary seed source was undertaken at several sites following seeding in 1981 and 1982. Results from this study concluded that competition from seeded cool season species, primarily intermediate wheatgrass, adversely affected the establishment and growth of species from the native hay mulch. However, when native hay mulch was applied to an un-seeded plot the resulting vegetation species mix included native forbs and sedges. Furthermore, observations in 1988 indicated that there was no significant difference in total plant production between the seeded and mulched, and the mulched-only sites. Accordingly, this study concluded that the use of native prairie hay as a mulch provides a source of complimentary seeds and is a viable reclamation tool deserving of more attention. Unfortunately no soil monitoring information was presented to complement the revegetation data.

8.2.5 Montane Grassland and Revegetation Trials, Jasper National Park

8.2.5.1 Background and Disturbance Type. The study area was selected to test the effectiveness of reclamation techniques in disturbed Montane grasslands (Wishart 1984).

A pipeline R-O-W in Jasper National Park, adjacent to Jasper Lake, was selected as the site for the revegetation trials. The pipeline was constructed in 1952. No steps were taken to salvage topsoil during construction, nor was the R-O-W reclaimed afterwards. Wind erosion has resulted in a predominance of gravels near the soil surface. The mean plant cover of the R-O-W was estimated at approximately 80% of adjacent undisturbed grasslands.

8.2.5.2 Objectives. The study site was selected for reclamation in order to test the effectiveness of top dressing, fertilizing and seeding method techniques. Both field and greenhouse trials were conducted.

8.2.5.3 Approach and Methods. In order to test the effectiveness of revegetation efforts, top dressing, fertilizer, seeding methods and plant materials were considered as independent reclamation variables and a split-plot experimental design was adopted. In the spring of 1977, the site was divided into four separate rows and then subdivided again into four levels of plot units which represented each variable. All plots were rototilled and hand raked to create a level seedbed.

To assess the affects of top dressing on revegetation the study plots were divided into three groups. Plots in one group were treated with fibric to mesic peat (from feather and sphagnum mosses) to a 10 cm depth. The second group of plots were top dressed with 7.5 cm of strongly calcareous, aeolian loamy sand material, similar to undisturbed surface soils in the area. The third group of plots were not top dressed.

Within each top dressing group, one half of the plots were fertilized. The other half were not fertilized.

Each of the fertilized and unfertilized treatment plots were further subdivided into four areas subject to different seeding methods: (1) broadcast seeding; (2) hand raking the seed into the seedbed; (3) packing the seed into the seedbed; and, (4) covering the seed with a cellulose fibre hydromulch.

Three seed mixtures were applied, each over a one metre square plot, within the four seeding method areas. Sixteen native species were applied within these mixtures at a rate of 20 kg/ha per mixture.

The research was designed to assess the response of plant species to the various treatments. In 1977/78 data on the percentage of ground cover, average plant height, vigour, soil fertility and grazing impacts at the trial sites were collected.

The field trial studies were supplemented by greenhouse trials to assess the effect of temperature and moisture on top dressing and fertilizer treatments.

8.2.5.4 Results and Discussion. Climate was an important factor in the establishment of vegetation in the first two years following reclamation. Both at a macro and micro scale climate is responsible for the moisture regime and thermal conditions required for plant growth.

The study showed that top dressing the seedbed was generally not beneficial for revegetation. Greenhouse experiments demonstrated that both peat and loamy sand top dressings were less fertile than the original soils, ultimately resulting in negative reclamation results. The peat top dressing was insufficiently thick to store the necessary soil moisture for revegetation. The loamy sand top dressing was similarly prone to droughty conditions and did little to improve the physical or chemical (fertility) characteristics of the soil.

Fertilizer applications were found to significantly improve seed production, plant maturation rates, ground cover and biomass values. This occurred only initially and over longer periods of time, the applied soil nutrients became unavailable to plants. However, the initial establishment of the vegetation allows for development of a productive plant-nutrient cycle which maintains the revegetation program subsequent to effective fertilization. Incorporating fertilizers directly into the seedbed, by raking or other means, was found to increase ground cover and plant biomass.

The method of seeding did not affect overall percent ground cover. Although differences in plant establishment in the first growing season and in the early part of the second season were noted, differences were soon obscured by encroachment of established vegetation. Overall, mulching was the poorest seeding method, possibly because the mulch retards the rate of soil warming in spring and available nutrients become immobilized by microorganisms decomposing the organic matter.

In conclusion the study determined that on a badly degraded site, simply broadcasting seed onto an unamended rototilled surface produced ground cover of 35% after two growing seasons - only 5% less than the best overall treatment. Therefore, if weather conditions are favourable during establishment, and if erosion can be controlled, proper seedbed tillage and broadcast seeding alone can be sufficient to successfully reclaim a site. Fertilization may be used to enhance the revegetation process, particularly if rapid plant growth is desirable to protect against erosion.

8.2.6 Native Vegetation Establishment at the Oldman River Dam Site

8.2.6.1 Background and Disturbance Type. The Oldman River dam, situated just east of the confluence of the Oldman, Castle and Crowsnest Rivers in southern Alberta, was completed in 1991 to regulate flows to provide a dependable water supply for domestic, municipal, industrial, agricultural and recreational use. Construction and operation of the dam and related facilities resulted in loss of vegetation and displacement of wildlife resources, therefore numerous mitigation programs were initiated to avoid or reduce

adverse impacts. The establishment of native vegetation at the dam site, documented by Smreciu and Hobden (1992), is reported in this case study.

8.2.6.2 Objectives. The aim of the reclamation plan was to establish self-sustaining native plant cover on the steep slopes of the dam face and abutments which would fit aesthetically with the surrounding landscape. Native plants indigenous to the area were used where possible as these were expected to be: (1) adapted to local site environmental conditions; (2) acceptable to local wildlife utilization; (3) aesthetically compatible with the local landscape; (4) self-sustaining and therefore requiring little or no maintenance once established; and, (5) less aggressive than introduced species.

The specific objective of Smreciu and Hobden's study was to document the establishment of the native plant community and to collect monitoring results on a regular basis.

8.2.6.3 Methods. The reclaimed substrate on the dam face consisted of approximately 1 m of closely packed, variable materials such as clay and pit run gravel, while the surface layers of the dam abutments were composed of material remaining after vegetation and topsoil was removed. These surface layers were tested and showed no substances believed inhibitory to plant growth (Carrington, pers. comm. 1992).

In early spring (1991), a toothed bucket of a backhoe was used to scarify the surfaces of both dam face and abutments. Vegetation material and associated topsoil from a nearby native wheat grass-spear grass-June grass community on a southern aspect below full supply level, was removed with a loader and spread immediately on the dam face at an approximate depth of 15 to 20 cm. Large rocks were removed and subsequently topsoil was packed using a Bombardier tracked vehicle.

All areas except the uppermost slope and abutments were fertilized with 10-51-0 fertilizer broadcast at an approximate rate of 2 kg/ha using an all-terrain vehicle. A mixture of equal parts of 'Walsh' western wheat grass, 'Revenue' slender wheat grass and 'Elbee' northern wheat grass was seeded with a Truax drill at a rate of approximately 5 kg/ha along with 2 kg/ha oats. On small areas or steep slopes, seed was broadcast and raked in by hand. Except for a small area on the west side of the dam, oat straw was spread at an approximate rate of 4938 kg/ha (2 tons/acre) and crimped into the topsoil. The cover crop was cut in July and September and all cut material was removed from the slopes.

On the upper most slope of the dam and the adjacent abutments, fertilizer and seeds were broadcast with a cyclone seeder and then packed using a D3 caterpillar. On these steeper slopes, straw was not crimped into the soil, however a wood fibre mulch and plant resin tackifier was applied. Irrigation water was applied to the upper slopes and abutments in mid to late summer (1991).

8.2.6.4 Results and Discussion. To determine re-vegetation success, nine 0.5 x 1 m plots were

placed at various locations and monitored on May 30, July 4, and August 22, 1991. Parameters monitored were abundance of cover crop and seeded wheat grasses, and amount of regeneration of native vascular plants. Table 16 shows the results of monitoring.

Native plants, including western wheat grass, blue grama grass, tufted white prairie aster, wild vetch, fringed sage, scarlet mallow, tufted fleabane and wild blue flax had successfully become established over the growing season. Additional species which established on site but were not seen on the plots were native prairie rose, green needle grass, purple prairie-clover, small-leaved everlasting, Colorado rubber-plant and introduced yellow goat's-beard. Most species appeared to have developed from root or rhizome material.

Additional observations were that the greatest diversity of non-seeded native plants occurred where straw had not been crimped into the topsoil. Emergence of seeded wheat grass was good in the absence of straw mulch and where oat cover crop abundance was low. It was poorer where the oat cover crop was thick. Relatively slow native plant establishment on the upper dam face and the abutments were attributed to several possible factors including later seeding date, lower seeding rate or different mulch treatment.

8.2.6.5 Monitoring. The study authors have planned future monitoring to follow the success of this reclamation beyond the initial stages, however funding is uncertain at this time.

8.2.7 Reclamation of Native Prairie Grassland Following Pipeline Construction in the Morley Flats Area of Alberta

8.2.7.1 Background and Disturbance Type. Canadian Western Natural Gas (CWNG) constructed a natural gas pipeline which traversed for part of its distance, an area called Morley Flats in the spring of 1991. Construction of the 323 mm pipeline required a burial depth of 1.1 m and an 18 m R-O-W. The study area is located at the transition of the fescue grass and montane ecoregions and is characterized by native grassland and mixed aspen forest cover. A soil survey and development and reclamation plan was completed for the project (Kerr and Morrison 1991). Within the Morley Flats area, soil development is characterized by shallow, gravelly soils which are rapidly drained, prone to droughty conditions and wind erosion. Of specific concern for reclamation of the native grassland was the ability to protect the shallow topsoil material from erosion or washing into voids in the gravelly subsoil as well as the high degree of surface and subsurface stones characterising the regosolic soils of the Morley Flats area. The case study discusses the specific reclamation efforts undertaken within this area.

8.2.7.2 Objectives. The objective of reclamation was to restore the R-O-W to a condition equivalent to the pre-construction condition. Ultimately, a self-sustaining native vegetation cover is desired to protect the soil from erosion and to be compatible with the surrounding landscape.

Table 16. Occurrence and Abundance of Seeded and Naturally Regenerated Plants in Ten Plots on the Downstream (South) Slope of the Oldman River Dam

PLOT 1	MAY 30	JULY 4	AUG 22
Agropyron smithii	0	t	1
Aster ericoides	1	t	1
Bouteloua gracilis	t	2	2
Erigeron caespitosus	0	0	t
Stipa sp.	0	t	0
Vicia americana	t	1	t
Wheatgrass (seeded)	t	2	10(fl)
Description: south aspect; lower slope; no mulch; 30 to 35% oats cover.			
PLOT 2	MAY 30	JULY 4	AUG 22
Artemisia frigida	0	t	0
Bouteloua gracilis	t	0	5
Sphaeralcea coccinea	0	t	0
Vicia americana	t	t	0
Wheatgrass (seeded)	t	t	5
Description: south aspect; mid-slope; mulched with crimped straw; 25% oats cover.			
PLOT 3	MAY 30	JULY 4	AUG 22
Koeleria macrantha	0	0	1
Wheatgrass (seeded)	1	5	5
Description: south aspect; mid-slope; mulched with crimped straw; 30% oats cover			
PLOT 4	MAY 30	JULY 4	AUG 22
Agropyron smithii	0	1	0
Koeleria macrantha	1	0	0
Vicia americana	t	t	t
Wheatgrass (seeded)	t	2-3	3
Description: south aspect; mid-upper slope; mulched with crimped straw; 4% oats cover.			

continued . . .

Table 16. Continued.

PLOT 5	MAY 30	JULY 4	AUG 22
Agropyron smithii	1	t	0
Aster ericoides	t	t	t
Bouteloua gracilis	2	1	1
Koeleria macrantha	t	0	0
Vicia americana	t	t	0
Wheatgrass (seeded)	1	3	20
Description: south aspect; upper slope; crimped straw mulch; 15% oats cover.			
PLOT 6	MAY 30	JULY 4	AUG 22
Bouteloua gracilis	0	t	0
Koeleria macrantha	5	0	0
Poa sp.	0	1	0
Symphoricarpos occidentalis	t	?	0
Weeds (annual)	t	2	5
Wheatgrass (seeded)	--	t	--
Description: south aspect; lower slope; crimped straw mulch; 15% oats cover.			
PLOT 7	MAY 30	JULY 4	AUG 22
Artemisia frigida	0	0	t
Vicia americana	0	t	0
Weeds (annual)	0	t	1
Wheatgrass (seeded)	0	1	3
Description: west aspect; mid-lower slope; wood fibre mulch held with a vegetable resin tackifier; 8% oat cover.			
PLOT 8	MAY 30	JULY 4	AUG 22
Atremisia frigida	0	0	t
Aster ericoides	0	t	1
Linum lewisii	0	0	t
Vicia americana	0	0	t

continued . . .

Table 16. Concluded.

Wheatgrass (seeded)	1	0	5
Description: south aspect; mid-lower slope; wood fibre mulch held with a vegetable resin tackifier; < 1% oat cover.			
PLOT 9	MAY 30	JULY 4	AUG 22
Artemisia frigida	0	0	t
Weeds (annual)	0	0	t
Wheatgrass (seeded)	0	5	4
Description: east aspect; upper slope; soil hard packed; wood fibre mulch held with a vegetable resin tackifier; 1% oat cover.			
Values presented are % coverage; t = trace coverage (<1%).			

8.2.7.3 Approach and Methods. On the Morley Flats area a three-phase soil stripping program was undertaken over the trench and soil stockpile area (9 m in width). No stripping was undertaken over the working side of the R-O-W. Stripping of the first two lifts was undertaken using an unmodified grader. Some testing was required to determine to what depth soil stripping could be consistently achieved given excessively stoney conditions. The first lift consisted of the topsoil horizon which averaged approximately 7 cm in depth and contained generally less than 10% gravels by volume. It was stripped with as much of the sod intact as possible with the idea that the sod would provide an abundance of seed propagules and rhizomes which would ultimately enhance the revegetation process. The first lift was stored on the existing native grassland sod at the edge of the working side of the R-O-W.

The second lift consisted of the upper subsoil horizon which was a mosaic of topsoil material and gravels. This lift was undertaken over the trench line only, to a total stripped depth of 25 cm.

The third lift was the excavation of the spoil material. This was done using a backhoe with narrow-width bucket to minimize the quantity of stony spoil brought to the surface. The materials from each lift were stockpiled parallel to the trench line and a minimum 1 m separation was observed between the piles.

The reclamation process consisted of backfilling the trench with the spoil material and compacting it as much as possible. Backfilling was undertaken using a backhoe with a Mormon board attached to the bucket. The second (subsoil) lift was reclaimed over the trench line and feathered out over the entire stripped area. This lift was replaced and lightly compacted using an unmodified grader. The entire R-O-W was seeded using a modified drill seeder and a straw mulch was applied to particular sections to protect

against wind erosion while also promoting the retention of soil moisture for germination and providing an additional source of organic matter. The seed mix consisted of the following: northern wheatgrass (13.9% by weight), slender wheatgrass (15.5%), Kentucky bluegrass (8.4%), sheep fescue (9.6%), creeping alfalfa (10.4%), sainfoin (24.3%) and June grass (15.9%). A high phosphate fertilizer (12-55-0) was applied to the reclaimed topsoil (between the first and second topsoil lifts) at a rate of 200 kg/ha. A follow-up amendment of high nitrogen fertilizer formulation (34.5-0-0) will be applied in the following growing season at a similar rate of application.

8.2.7.4 Results and Discussion. Stripping of the first lift (topsoil) as a sod layer proved to be a valuable technique for enhancing revegetation. Grasses began to grow on topsoil piles almost immediately following stripping, thereby helping to protect it against erosion.

During the period prior to initial establishment of a vegetation cover the straw mulch was effective in protecting the topsoil against erosion. It was difficult to determine if the mulch aided in seed germination as the spring was unusually wet in 1992 and germination was achieved with great success.

Visual observations of the R-O-W in July and September, 6 weeks and 15 weeks after seeding, indicated that straw mulch had provided a good vegetation cover to protect the soil from erosion. In places, volunteer establishment of oats from the straw mulch material had resulted in a nurse crop, further stabilizing the soil surface. Mowing and removal of oat seeds may, however, be required in the following growing season to reduce competition with native seeds. A mosaic of native species was also present, resulting from both the natural seed propagules and rhizomes from the sod, as well as the seed present in the seed mix. Follow-up observations during the following growing season will better assess the success of the native species revegetation. More formalized vegetation data will be collected to compare on and off right-of-way conditions.

Surface stoniness on the R-O-W was approximately equivalent to that of the surrounding landscape. Follow-up observations during the following growing season will determine if further removal of surface stones is required.

8.2.7.5 Monitoring. Follow-up monitoring of the R-O-W has been recommended to document the success of the three-phase stripping procedure and the revegetation with native species program over both the long and short term.

8.2.8 Reclamation of Mixed Grass Prairie Disturbed by Pipeline Construction

8.2.8.1 Background and Disturbance Type. Because of the growing interest in protecting and conserving prairie ecosystems, efforts are ongoing to develop appropriate procedures to minimize the disturbance to native rangeland during pipeline construction. One source of concern to Alberta Public Lands Division Range Specialists has been the long-standing regulatory requirement for topsoil salvage, with all or partial right-of-way

stripping (Adams 1993). While recognizing the need for and benefits of topsoil salvage in many circumstances in the province, this practice may be detrimental in those regions with shallow topsoil and/or Solonetzic soil conditions. Stripping results in a wide zone of disturbance and destruction of the existing native plant community. Where the stripped zone is subsequently seeded with non-native species, as has often been the case in the past, these seeded areas provide preferred grazing areas for cattle, thereby creating distribution problems for the rancher. In contrast, certain species used in revegetation seed mixes such as crested wheatgrass, can become unpalatable over time and are no longer grazed. Because of our current lack of knowledge regarding appropriate technology, seeding stripped pipeline R-O-Ws with native species cannot always be relied upon to restore the disturbed area to a compatible cover (Adams, pers. comm. 1992). Public Lands staff theorized that range productivity in dry mixed grass or mixed grass ecoregions may be higher on unstripped pipeline R-O-W's than on stripped, seeded R-O-Ws. Research is currently being conducted in the mixed grass prairie at the Scope reservoir, Grand Forks and Manyberries area to compare revegetation success between stripped and non-stripped pipeline rights-of-way. Comparisons are also being made on reclamation success between ungrazed and grazed areas, and native and agronomic seed mixtures. However only the stripped versus unstripped experiment results will be described here.

8.2.8.2 Approach and Methods. To test the hypothesis that productivity would be higher on unstripped versus topsoil stripped sections of the R-O-W, plots were set-up in three different areas of mixed grass prairie. At each field location, a 400 m section of pipeline R-O-W was subdivided into four 100 m sections and then each 100 m section into three equal units of approximately 33 m each. One half of the 400 m section was designated for the topsoil stripping and the other half for the non-strip treatment. This results in 12 equal size cells.

After pipeline construction, stripped and unstripped sections of the pipeline R-O-W were seeded using a TRUAX rangeland drill. Within each 100 m segment, the first cell was seeded to crested wheatgrass, the second to a mixture of native grasses (northern wheatgrass 25% by weight; western wheatgrass 30%; green needlegrass 20%; June grass 5% and slender wheatgrass 20%) and the third was left unseeded. The native mixture was seeded at 14 kg/ha (12.5 lb/ac) with a 15 cm row spacing.

After seeding was completed, barbed wire fence was erected around the two central 100 m segments, leaving only the outer two segments available for livestock grazing. The twelve cells were described in terms of species composition and cover estimates, including percent soil exposure, in late summer during 1991 and 1992. Data were collected according to four discrete zones within each of twelve cells. These zones relate to pipeline construction and include the work side, the spoil side, the trench line and a check or control area.

8.2.8.3 Preliminary Results and Discussion. At the Grand Forks test site, a sandy Orthic Brown soil is characteristic of the undulating topography. The undisturbed plant community was dominated by needle and thread, blue grama grass, sandgrass and scurf pea. The first plant cover to establish on the R-O-W in 1990 (following pipeline construction on May 15 and seeding on July 23) was prickly pear cactus which was spread back on the soil surface during replacement of topsoil. In the latter part of 1990 and through 1991, a dense cover of Russian thistle and other annual weeds were predominant but by 1992, "an excellent establishment of native grasses was apparent and a marginal stand of crested wheatgrass" (Adams 1993). In terms of the range plant community, expressed as a percent of the control, the non-stripped spoil area was approximately 60% of the control and the unstripped work area was about 90% of the control. On the stripped treatment the plant community in the work and spoil was about 50% of the control. In summary, there was a greater net reduction to the plant community with stripping than without stripping.

At the Scope reservoir site a fine sand loam Orthic Brown soil supports a plant community dominated by needle-and-thread grass, blue grama grass, june grass, fringed sage and scarlet mallow. Establishment of seeded species was very poor given the late summer seeding date (June 1991). Soil exposure was highest on the trench line and slightly higher with grazing, similar to the Grand Forks area. Again, the percent plant community was slightly higher on the non-stripped versus stripped soil treatments.

At Manyberries a fine loamy Brown Solid has developed on a gently undulating topography. The native plant community consists of northern wheatgrass, june grass, blue grama grass and fringed sage. Micro-site variation associated with the Brown Solod soil profile made soil handling extremely difficult. There were no clear trends with respect to soil exposure due to soil treatment although soil exposure was uniformly high on the trench line and spoil area. The relative degree of soil disturbance was similar in terms of stripped or unstripped due to the packed surface of range sites. No clear trend could be established in terms of disturbance to the plant community. Overall the extent of soil disturbance was greatest in the trench and spoil area and least in the work area.

8.2.8.4 Monitoring. Further investigations of the sites are proposed to document the success of native prairie revegetation methods. Preliminary results indicate the need for such examination in light of changing reclamation and/or restoration objectives by industry and range managers alike and our lack of long-term monitoring data on comparative techniques. The study will be presented in an upcoming RRTAC report.

9. RECOMMENDATIONS

On the basis of the review of some 400 documents, and discussions with personnel involved in grassland restoration and/or reclamation throughout the prairie provinces, recommendations regarding advancement of knowledge in this field focus on management and research issues. Many of these recommendations follow those put forward in the Prairie Conservation Action Plan (Prairie Conservation Coordinating Committee 1991).

9.1 MANAGEMENT RECOMMENDATIONS

1. **Protect existing areas of native prairie within each ecoregion** to provide a basis for research and comparison of restoration/reclamation efforts. Protection in this sense should include government, non-government agencies and private landowners in the establishment of such ecosystem reserves.
2. **Develop an integrated, ecological approach to grassland restoration/reclamation on a site-specific basis.** This approach stems from a recognition of the complexity of functioning grassland ecosystems where reclamation or restoration requires on attention to the details of climate, terrain, slope, soil, vegetation, land use, and time. It requires a knowledge of cause-effect relationships between environmental forces and the plants and animals which make up the grassland.
3. **Re-establish native prairie plants** on land disturbed by industrial or agricultural activities where these activities have ceased.
4. **Develop a comprehensive management plan** which defines restoration/reclamation goals and strategies for achieving these goals. A number of steps are involved:
   i. **Determine specific site objectives** e.g., sustain maximum vegetation productivity and community diversity or restore and revegetate surface disturbance to predisturbed conditions as required by reclamation requirements.
   ii. **Conduct a biophysical inventory.** This may involve mapping and describing terrain, slope, soil and vegeta-

tion conditions prior to disturbance. The resulting inventory provides a basis for site-specific reclamation methods and procedures within a regional context.

iii. **Define management actions and procedures.** This involves the evaluation of project feasibility in terms of financing, technical assistance, available time, labour and responsibilities. Specific reclamation and restoration methods and procedures should be selected for specific areas, project scheduling should be determined and equipment, seed mixes and rates of application determined based on the objective of the plan.

iv. **Monitor results and evaluate.** Monitoring of the reclamation/restoration project is essential in order to determine the success or failure of the program in meeting the objectives. Monitoring should include a systematic approach to data recording and analysis to address both long and short term objectives.

5. **Integrate reclamation/ restoration plans with neighbouring land uses** where appropriate e.g. livestock grazing, wildlife habitat uses.

6. **Provide an inventory of native prairie based on ecological land classification principles.** The inventory should be produced at a scale useable for land use planning purposes (a 1:250 000 mapping scale would be appropriate). The inventory shoul include the type and extent of all surface disturbances in native prairie areas.

7. **Monitor the location, nature, extent and quality of the native prairie** to allow management objectives to be developed for each grassland ecoregion.

8. **Make grassland ecoregion inventories available to all user groups** for integration with local land use, development, zoning and recreational planning activities.
9. Provide opportunities for wildlife and land managers to participate in **seminars and workshops on identification and management of native prairie ecosystems.**
10. **Develop and implement extension programs to assist landowners in the conservation of native prairie.** Cooperation between the federal and provincial governments and non-government organizations is required. Incentives and land use policies should similarly encourage landowners to leave lands in a natural state.

9.2 RECLAMATION AND RESTORATION RESEARCH RECOMMENDATIONS

1. Develop a centre of prairie grassland research to direct and focus applied research on native prairie ecosystems in general and reclamation/restoration in particular. The centre should bring together government, industry and researchers to work on a cooperative basis.
2. Establish habitat requirements for specific native grassland species.
3. Determine the interrelationships between native and non-native grassland species in terms of establishment and maintenance.
4. Determine the optimum rate of seeding for individual species and under different environmental conditions.
5. Examine effective means to control exotic (weed) species.
6. Determine cost-effective means to produce and harvest native seed sources.
7. Determine the suitability of incorporating fire and grazing into the restoration/reclamation plan.
8. Examine the role of cover crops in reclamation.
9. Examine the benefits/drawbacks of fertilizer amendments.
10. Examine the successional trends of natural and enhanced vegetation recovery.
11. Examine requirements in the areas of biotechnology, plant breeding, propagation and cultivation.

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10.1 PERSONAL COMMUNICATIONS

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APPENDIX II

THE ROLE OF FIRE IN THE ECOLOGY OF NATIVE PRAIRIE GRASSLANDS

Background. Fire is an important factor in the ecology of prairie grasslands. Researchers have described the role of fire in terms of both a natural, dynamic process in the grassland ecosystem (Hulbert 1969; Lamotte 1983; van Andel and van der Bergh 1987), or alternatively as an unnatural disturbance which significantly alters successional processes (Collins 1987; Evans et al. 1989). In either case, fire has continued to play a significant role in determining the nature of the prairie grassland ecosystem through both natural and man-induced fire events.

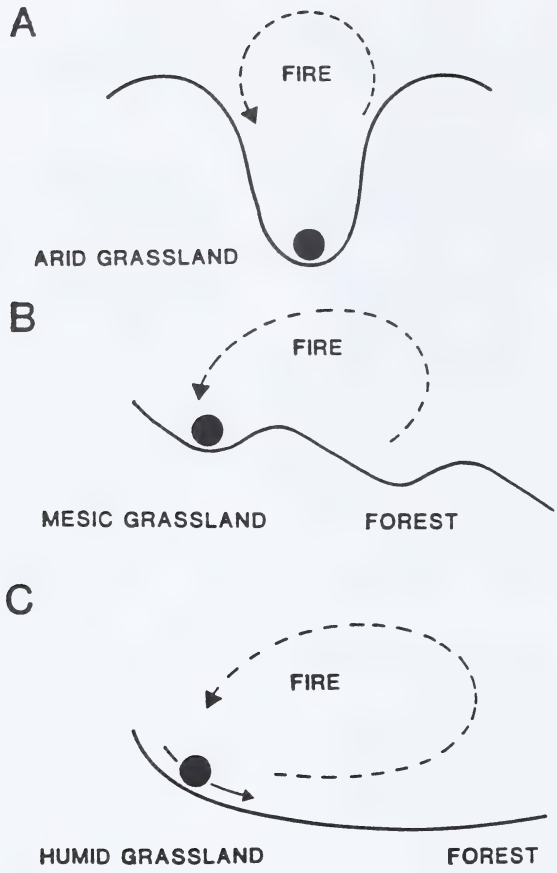
Use of fire by North American aboriginal people has been well documented, where fires were set for a variety of reasons: to aid in hunting; to make travel easier in the spring; to encourage grass growth for grazing animals; to control the invasion of woody species; to reduce invertebrate pests; and to control migration paths of game (Anderson 1976).

Increase in fire frequency during 1880 to 1920 due to settlement and railroad building created a backlash to suppress fires, which was very successful and has resulted in grasslands existing without frequent fire for more than 70 years (Nelson and England 1971). The result is a changing grassland ecology where native prairie still exists, but with many of the fire-adapted species subject to encroachment by tree and shrub growth and colonization by annual and introduced species. Grassland areas receiving precipitation in excess of 635 to 762 mm annually show a decline in productivity through excessive litter accumulations as well as from invasion by woody and introduced species.

The specific effects on the vegetative composition of grasslands are varied and dependent on the plant species involved, climatic patterns, site conditions, the nature of the substrate, the quality of the grassland and the timing and intensity of the burn. Many of the impacts of fire are beneficial and can result in some or all of the following (Trottier 1992):

1. remove unpalatable dead plant matter;
2. enhance flowering, seed production and increase seed germination; thus stimulating successional regrowth;
3. topkill trees and shrubs;
4. maintain browse at a height that grazers can reach;
5. reduce extreme fire hazards;
6. create an appropriate seedbed;
7. control and reduce undesirable introduced grasses and forbs;
8. control insect pests;
9. return nutrients to the system as a natural fertilizer, and
10. increase the component of broadleaf plants, including many nitrogen fixers

Response of Prairie Grasslands to Fire. A generalized conceptual model of how fires influence native grassland ecosystems depending on climatic conditions is presented in Figure A1. In an arid



The influence of fire depends upon the intrinsic properties of the system, as well as other external inputs. In (A) an arid grassland (e.g., shortgrass prairie) remains a grassland regardless of the presence or absence of fire. In (B) a grassland (e.g., mixed grass prairie in some cases) may be invaded by woody species if a seed source is available. The same climatic variables may support either system (a case of multiple stable points), but fire will drive the system to a grassland. In (C) a humid grassland (e.g., tallgrass prairie), with moist climate and woody seed sources present, is converted to forest unless fire intervenes.

Figure A1. Conceptual Model of Grassland Response to Fire.
(Source: Evans et al. 1989)

grassland, such as the dry mixed grass ecoregion (situation A), the system remains that of a grassland regardless of the presence or absence of fire. In a grassland with more mesic conditions such as the mixed grass ecoregion (situation B), the suppression of fire may result in an invasion by woody species, providing a seed source is available, resulting in the system becoming that of a shrubland or forest. The same climatic variable may support either a grassland or woodland, but fire will drive the system to that of a grassland. In a humid grassland such as that of the tall grass prairie or aspen parkland and adjacent fescue grassland ecoregion (situation C), with a more mesic climate and an available woody seed source, the system is converted to that of a woodland unless fire intervenes (Evans et al. 1989). The intervention of fire after the area has succeeded to a forest will likely not be sufficient to drive the system back to a grassland state.

Vegetation Effects. Much of the research on the effects of burning prairie grasslands has been conducted in the tall grass prairie. Curtis and Partch (1950) and Ehrenreich and Aikman (1957) reported an increase in the number and height of seedstalks of native grasses as a result of burning. Further studies were conducted by Ehrenreich (1959) in Iowa to investigate the effects of burning on the growth of certain native prairie grasses. The three chief dominants of the upland prairie community were prairie dropseed (*Sporobolus heterolepis*), little bluestem (*Andropogon scorparius*) and big bluestem (*Andropogon gerardi*). Prairie dropseed and little bluestem are bunch grass dominants of the upland prairie. Big bluestem, a lowland prairie sod-former, dominated much of the area between bunches. Porcupine grass (*Stipa spartea*), formed numerous smaller bunches, as did June grass (*Koeleria cristata*). Other species present included Indian grass (*Sorghastrum nutans*) and Canada wild rye (*Elymus canadensis*). The prescribed burn was applied in late August and comparisons with a control site were made.

The results were as follows:

1. The number of seedstalks per grass bundle was considerably greater for big bluestem, little bluestem, Indian grass and prairie dropseed on the burned area than on the unburned area. The burn did not appear to affect Canada wild rye.
2. With the increase in the number of seedstalks per bundle, there was a corresponding increase in number of fruits.
3. The germination percentage was very low for all species, but was slightly greater on the burned area for big bluestem, little bluestem and Indian grass. There was no germination at all on the unburned area for little bluestem. The low germination rate likely related to inadequate maturity of the seeds.
4. There was little difference in the amount of photosynthetic area on plants from the burned and unburned area. However, total

biomass was greater from the burned than from the unburned area for all species except Canada wild rye, in which there was no difference. The greater biomass was attributed to the greater number of seedstalks which resulted from the burn. Curtis and Partch (1950) reported a six fold increase in the number of seedstalks of dominant and principal subdominant grasses as a result of burning, and a 60% increase in height. An increase in seedstalk production could also be simulated by the removal of large quantities of litter and duff, the addition of ash or a stimulation of floral bud induction resulting from the direct heat of the fire or higher temperature in early spring.

Earlier growth following a burn has also been observed (Aldous 1934; Ehrenreich and Aikman 1957) which may have a physiological effect on the plants leading to increased flowering.

Some other species which are found commonly throughout the prairies have also been studied as to their response to fire. Cool-season grasses such as *bromus*, *elymus* and *poa* do not benefit and actually may be harmed by spring burning. Kentucky bluegrass can be almost eliminated by spring burning, (Svedarsky et al. 1986).

Effect of Fire on Shrubs. Recurring fires generally favour grasses and herbaceous species over woody plants and shrubs (Vogl 1974). Most fire-adapted or fire-tolerant woody species cannot sustain large populations in grasslands subjected to intense fires on a frequent basis. Regardless of whether the plant is actively growing or dormant, fire will damage living tissue of woody vegetation.

Fire has been used commonly in rangelands to remove shrubs of low forage value (Stoddart et al. 1975; Vallentine, 1989). Control of fire over approximately the past 70 years has resulted in an unprecedented increase in woody plants on grassland, to the advantage of big game populations but to the detriment of the carrying capacity of the rangeland for cattle. There is a recognized need for more controlled burning to maintain grasslands and reduce shrubland encroachment (Bailey 1976).

Plant age, soil moisture at the time of burn, intensity of fire, season of burn, health of the shrub species and frequency of droughts are important variables in determining the methods and success of a planned burn.

Western wild rose (*Rosa woodsii*) is a fire tolerant species. Prescribed burns effectively reduced the cover of this shrub, with a 2 to 3 year recovery period. Raspberry (*Rubus* spp.) increases after a fire, especially following hot burns. Choke cherry (*Prunus virginiana*), serviceberry or Saskatoon (*Amelanchier alnifolia*) and snowberry (*Symphoriocorpus albicaulus*) all sprout vigorously following a burn (Miller 1963; Wright and Bailey 1982). Fire may reduce the abundance and vigour of silverberry. Annual spring burning is often used to control shrub invasion of Canadian grasslands (Bailey 1976). However, frequency and stem densities of serviceberry and prairie wild rose (*Rosa woodsii*) generally increase on annually burned areas in Alberta. Western snowberry and wild raspberry

(*Rubus strigosus*) declined in frequency on areas burned annually, but no shrubs were eliminated.

Blackberry (*Rubus* spp.) can be eliminated with 2 to 3 successive years of burning in late spring. Two cool-season fires (spring and fall) consistently reduced densities of currant (*Ribes* spp.) in the immediate post burn phase, but western red currant resprouted readily after a burn (Bailey 1978b).

Big sagebrush (*Artemesia tridentata*) is fire sensitive and can be effectively controlled by burning. Silver sagebrush (*A. cana*) is completely topkilled with spring and fall burns, regardless of the fire intensity. This was most effective under dry fall conditions after sagebrush plants had completed their growth and reproductive cycles (Bailey 1978b).

Cacti are relatively fire susceptible; plains prickly pear (*Opuntia polyacantha*) is adversely affected by repeated burning (Martin 1983). Fire has been used successfully in Texas to control the density of seven out of eight cacti species. This was due to the direct effects of the burn as well as increased mortality due to insects, rodents, disease and increased palatability to cattle. In the rangelands of eastern Wyoming, fall burning of prickly pear was found to be much more effective than spring burning (Dodd et al. 1985). In Alberta, fire damaged prickly pear was consumed readily by pronghorned antelope.

Late-spring fire has been a very effective method of controlling Kentucky bluegrass, without reducing the herbage of many of the warm-season grasses, although this was more effective on exposed ridge sites but did little in more depressional and mesic sites. Spring burning was much more effective than fall burning (Dodd et al. 1985).

The environmental effects of fire on prairie wetlands has been little studied and is poorly understood. However, there is general consensus that wetlands often become choked with emergent vegetation and are in need of manipulation to increase cover interspersion (Linde 1969). Fire has been used in many areas to control woody plant encroachment into wetlands. In Wisconsin, it has been successfully applied in the fall and winter to control undesirable vegetation (Vogl 1967) and/or when the substrate soils were dry. Burning has also been used to control plant succession within wetlands and to promote the aquatic plants that produce seeds and roots for waterfowl foods thus improving these sites for waterfowl habitat (Yancey 1964). Some plants successfully managed by fire in prairie wetland environments include Phragmites (*Phragmites communis)* - an aggressive perennial of little value to waterfowl, which can be controlled by fire; Whitetop (*Scholochloa festucacea*) - an excellent species for waterfowl use which can be enhanced with prescribed burning; Cattail (*Typha* spp.) - which often forms monotypic stands reducing habitat value (Yancey 1964). Carefully prescribed burning, especially in the winter over ice or when the substrate is dry, will reduce Cattail cover significantly; Bulrush (*Scirpus* spp.) - prescribed burns applied over ice are effective. Stands of sedge (*Carex* spp.) and spikerush (*Eleocharis* spp.) were little affected by burning (Yancey 1964). It appears that prairie wetlands can be enhanced with properly timed, less intense burns. However, a slow moving fire which burns deep into the dry

organic substrate of a wetland can have a severe impact on all hydrophytes.

Effects of Fire on Insects. Because grasshoppers are the principle above-ground insect consumers, the effect of fire on grasshoppers has been studied extensively. Comparing variously timed spring burns, late spring burning was found to be most effective whereas early spring burning actually increased grasshopper populations and caused earlier emergence (Knutson and Campbell 1976).

Although it is generally agreed that fire causes an immediate decrease in most insect populations (except ants and other deep underground insects) most studies found that a single spring burn increased total arthropod density and biomass (Nagel 1973). Several studies indicate that, regardless of the timing of the burn, burned areas eventually become more productive in terms of arthropod populations. This has been related to more productive vegetation and root densities on the burned areas (Lussenhop 1976).

Soil Response to Burning on a Prairie Grassland. The initial impact of fire is to decrease soil moisture due to the removal of protective thatch and vegetative cover. This material increases moisture infiltration and retention, traps snow, and reduces evaporative losses. Soil moisture values generally decrease during the year immediately following the burn (Kelting 1957).

Fire can increase or decrease soil nutrient levels depending on the intensity and duration of the burn. Two obvious effects are volatilization of certain elements and the modification of soil particles due to heat. Volatilization sends carbon and oxygen into the atmosphere along with varying amounts of sulphur and phosphorus, depending on the composition of the organic matter and the degree of combustion (Raison 1979). Nutrients in mineral form are affected by the changing physical properties of soil particles induced by heating and subsequent cooling. When micaceous minerals and clays dehydrate or fracture, the solubility of elements such as phosphorous and potassium can increase or decrease (White et al. 1973).

Chemical changes at mineral surfaces can be caused by the production of alkaline or alkaline earth compounds from the heated minerals or by organic matter combustion The solubility of phosphorus and potassium can increase or decrease depending on the chemical compounds formed when the material cools. Rapid heating and cooling may break a mineral apart as it expands or contracts. Fresh unweathered surfaces generally release these elements more rapidly than weathered surfaces.

Although an overall increase of most cations is well documented, fire can induce losses in some cases. Losses may be due to increased surface erosion (Wells et al. 1979), movement below the root zone from leaching (Stark 1979), dilution effects from increased runoff (DeBano and Conrad 1978), and losses in fly ash (DeByle 1976). These findings confirm that the actual effects of fire on soil nutrients at any given site or time will be variable depending on the condition of the vegetation, character of the soil and topography, climatic factors and the intensity and duration of the burn.

In addition to adequate total nutrient levels, the availability of nutrients must also be high if plants are to benefit. One consequence of fire is that water-soluble cations are made immediately available for plant uptake (Raison 1979; Wright and Bailey 1982). Fire can result in the loss of nitrogen through volatilization (DeBell and Ralston 1970; Sharrow and Wright 1977; Tiedmann and Anderson 1980). The intensity of the burn and the amount of green material and fuel moisture level have been reported to influence the amount of nitrogen lost through volatilization (Dunn and DeBano 1977). Nitrogen decline has been noted for the litter, and upper organic-rich soil horizons when temperatures exceeded 200°C (White et al. 1973).

Although there is evidence that nitrogen in organic matter is volatilized, some authors report an increase in total soil nitrogen (including organic nitrogen, nitrate and ammonia) after a fire (Vlamis and Gowans 1961; White and Gartner 1975). Nitrate and ammonia levels have also been found to increase after a fire. The reported increases in all forms of nitrogen could be due to stimulation of legume growth (Mayland 1967), the washing of charred surface material into the soil (Metz et al. 1961), formation of ash which increases the growth of nitrifying bacteria (Burns 1952), and increased growth of nitrogen-fixing microorganisms (Isaac and Hopkins 1937).

Phosphorus is another nutrient released by burning. Schripsema (1977) found the availability to vary by site. Others have found availability to increase (Christensen 1976; Kramer 1973; Raison 1979; Smith and Owensby 1973; White and Gartner 1975). White and Gartner (1975) found an increase in available P only if temperatures did not exceed 200°C, after which volatilization likely occurs. They also speculated that, as for ammonia, soil moisture and heat determine the extent of the increase in phosphorus availability.

Comparatively few studies assess soil nutrients other than nitrogen and phosphorus. Availability of potassium (K), calcium (Ca), and magnesium (Mg) may increase after fire (Christensen 1976; Raison 1979). Soluble K will increase in the litter, and surface organic horizons if temperatures do not exceed 200°C (White et al. 1973). Ohr and Bragg (1985) found that Ca, iron (Fe) and manganese (Mn) decreased. However, they also found that if the plot was burned in consecutive years, that K, copper (Cu), Fe and zinc (Zn) availability increased. This was attributed to different rates of plant uptake for each nutrient, over time.

An increase in the pH has been attributed to ash accretion (Ahlgren and Ahlgren 1960; Smith 1970) The response depends on the amount of ash and the buffering capacity of the soil and is considered negligible in grasslands (Nye 1959; Tryon 1948).

Although the increase in nutrient levels and availability has been well documented, the effect a fire has on soil microbes and residues is also important. Bacterial populations decrease after a burn but increase three to ten fold within a month because soil temperature and nutrients for their growth are more favourable after a burn (Jurgensen et al. 1979).

Litter removal and the dark scorched surface cause soils temperature to increase. This

higher temperature has the effect of shortening the oxidative process and is believed to be the main effect fire has on surface organic matter (Harvey et al. 1976). This coincides with Hulbert (1969) who found that the major short-term effect of fire was the removal of litter rather than the fire-induced nutrient changes. Comparisons between a burned and a clipped plot indicated that the removal of mulch explained renewed vigour in burned stands. However, this pattern was not consistent over time and after four years of seasonal clipping and burning on the separate sites, the clipped site showed an eventual decline in productivity.

Fire has been found to affect many soil properties including pH, cation exchange capacity, organic matter oxidation, nutrient levels and availability, soils temperature and soil organism activity. These factors both in isolation or acting together, determine availability of soil nutrients and plant benefits from fire. The interaction of these factors needs to be understood in order to improve the use of fire in grassland management and reclamation.

Examples of Fire Response Within Grassland Dominant Ecoregions

Dry Mixed Grass Ecoregion (Grama Spear Grass).

In the more arid regions of the mixed prairie (i.e., sites which receive 25 to 40 cm of precipitation annually), fire can result in decreased herbage yield and critical reductions in litter. However, effects differ, primarily with season of burning, pre- and post-burn precipitation levels and plant species composition (Clarke et al. 1943; Coupland 1973). Fire applied in the early spring has been used successfully to eliminate or reduce cool-season species such as annual brome grasses, and to increase the yield of the warm season plants such as blue grama and sand dropseed. In general, spring burning resulted in higher total productivity than fall burning.

Following a spring wildfire, during dry soil conditions, the recovery time for a buffalo grass-bluegrama community was three full growing seasons (Wright and Bailey 1982). Other species in the community, in addition to the dominant grasses, were similarly affected.

A study carried out in southern Alberta found that fall burning of a dry mixed grass prairie appeared to require a shorter recovery time, with recovery completed by the end of the second year (Clarke et al. 1943). It has also been noted that dry mixed grass areas with heavy litter accumulation were severely damaged by burning, based on basal cover and forage production, compared to lighter damage in areas of less litter accumulation. Initial reduced production on a dry mixed grass prairie following a fire is attributed to:

1. partial killing of the vegetative stock;
2. reduction of plant vigour of the remaining forage plants, and
3. reduced moisture penetration associated with reduced ground cover and greater evaporation of soil moisture.

Studies of fires within the dry mixed grass prairie suggest that burning is generally undesirable because production and ground cover are

both reduced in a region where drought conditions have resulted in relatively low biomass, low growth rates and a short growing season dependant on precipitation. Further, recovery time following a burn in the dry mixed grass prairie is considerable (Clark et al. 1943). Prescribed burning should probably be conducted in this region only during wet years and fall burning may have the best results in terms of maintaining the native forage species. Timing and the intensity of a burn along with a knowledge of site and climatic conditions are crucial in the success of prescribed burning within this ecoregion.

Mixed Grass Prairie (Spear-Grama Wheatgrass).

Prescribed burning within the mixed prairie ecoregion is becoming more common and more controversial as a management technique (White and Currie 1983). One benefit of this is the possibility of increasing the utilization by livestock (Wright and Bailey 1982). Again, the timing of the burn is critical to many of the species, with a mid- and late-spring burn favouring big bluestem. Species responding well to early spring burning included blue and hairy grama grass. Kentucky bluegrass was nearly eliminated from test treatment sites regardless of the time of burning (Anderson et al. 1970). Periodic droughts have a strong and negative influence on the recovery of mixed prairie grasses after a fire (Hopkins et al. 1948; White and Currie 1983; Wright and Bailey 1980).

Within mesic sites of the mixed prairie, the effect of fires has been studied with the different results from fire effects on a dry mixed grass prairie. In one study, mid-May and mid-June fires reduced Kentucky bluegrass and green needlegrass. Vegetation on areas to which two burns had been applied began growing earliest, matured earlier and produced more flower stalks. This was attributed to a decrease in litter and higher soil temperatures. Grass growth began earlier and the number of native flowering plants increased. This occurred in the first growing season but thereafter rates declined until the third growing season (Ehrenreich and Aikman 1957). Overall, the vegetative growth response of the mesic site was more favourable than that of a dry mixed grass prairie. Another study showed that several of the major grasses harmed by fire in more arid areas were found to actually increase in cover in more mesic areas following a burn (Kirsch and Kruse 1972). Cool season grasses such as slender wheatgrass (*Agropyron trachycaulum*) and smooth brome (*Bromus inermis*) can be controlled with a spring fire and the warm-season grasses can benefit from fire. Further, shrubs can be setback from a prescribed burn. Where snowberry is a problem, Pelton (1953) felt that periodic burning would favour this species but that annual burning would harm it. The frequency of fire is important, especially in reducing the encroachment of trees and shrubs, but in areas subjected to periodic droughts, frequent burning may be detrimental to the favoured species.

A variety of observations have been made on the effects of fire on a mixed grass prairie (Higgins et al. 1986). Results often varied depending on the species composition, site conditions and timing of the burn. However, some general statements were made regarding the

effects of fire on mixed grass prairie species following prescribed burning:

1. big bluestem increased in herbage during all periods of spring burning;
2. little bluestem was also productive under burning, but less than that of big bluestem;
3. blue grama yields increased after spring burning;
4. responses of Stipa species varied with spring burning;
5. prescribed spring burning increased production of many warm-season grasses in the mixed prairie (i.e., those species which break dormancy later in the spring, after the burn has been applied). These increases varied depending on rainfall and litter accumulation prior to and after burning;
6. the time of burning is critical and may affect certain species in a variety of ways because of differing phenological characteristics.

Prescribed burning has rarely been used as a resource management tool in the mixed prairie of the Northern Great Plains as most of the vegetation is located within comparatively arid areas where there is rarely a problem of heavy litter build-up (Bailey 1978a). Often, following either a prescribed or natural fire, a decrease in herbage and productivity is attributed to a reduction in soil moisture recharge during the winter period or during a dry season following the burn. In the winter, following a fall burn, snow may be blown away from the burned area as fire had removed the vegetation cover which normally traps and allows for snow accumulation (DeJong and MacDonald 1975).

The final assessment of prescribed burning on a mixed grass prairie is that it is a viable management technique as long as it is carefully applied with an understanding of the species composition of the site to be burned and how these species will react to seasonal burns. Further, mixed grass prairie grassland should not be burned under drought conditions (Higgins et al. 1985).

Aspen Parkland (Rough Fescue Grassland), Fescue Grassland (Rough Fescue-Parry Oatgrass) and Montane (Douglas fir-Mixed Grassland).

The Fescue grasslands of central Alberta and Saskatchewan are part of the aspen parkland, with the relative abundance of rough fescue (*Festuca scabrella*) varying with climate, soil and grazing pressure. Rough fescue formerly dominated the zone of black soils on the northern fringe of the aspen parkland but has virtually disappeared due to cultivation or tree encroachment. Moss (1932) documented that burning had effectively stopped tree advancement in the Alberta aspen parkland. He predicted that in the absence of fire, succession would soon produce a considerable extension of the aspen (*Populus tremuloides*) forest. Further, the rate of bush encroachment and subsequent reduction of Fescue grassland has also increased in response to fire suppression (Bailey and Wroe 1974; Johnston and Smoliak 1968).

In view of these documented observations, a study to determine the effect of spring and fall prescribed burning on species composition and productivity of the rough fescue-western porcupine grass community was completed (Bailey 1978b). Results indicated the following:

1. following the first growing season, only a slight change in the total canopy coverage of the rough fescue-western porcupine grass community occurred, after either a spring or fall burn. The canopy coverage of grasses and grass-like species decreased while coverage of perennial forbs increased.
2. weather, litter accumulation and soil moisture conditions are generally more favourable in spring than in fall for burning aspen forests and adjacent grasslands.
3. burns intense enough to kill trees and shrubs could be conducted from about April 25 to May 10, in most years. However, burning at this time would reduce production of rough fescue for 2 or 3 years, after which time it would recover to pre-burn cover. One solution is for prescribed burning of grassland to be conducted in mid-April before dormancy of the grasses is broken, followed 2 weeks later by burning of the aspen forest. The timing of these burns would likely vary with seasonal conditions and location.

Johnston and MacDonald (1967) reported that seed set of the bunch type fescue of the southwestern foothills was determined during the August - September period of the previous growing season. Burning three months prior to induction and initiation of the floral primordia did not affect seed head production of rough fescue.

The canopy coverage of western porcupine grass, a warm season grass, was not affected by spring burning. However, seed production was stimulated for at least 3 years. Fall burning reduced canopy coverage and seed production of western porcupine grass. In Idaho, needle-and-thread grass was damaged by fall fire as it was still growing (Wright 1971).

Daubenmire (1968) reported from many sources that burning favours forbs over grasses; these findings were in agreement with other findings but found more specifically that the favourable response was from perennial forbs rather than from annuals, except for the annual, blueburr (*Lappula echinata*). The perennial forbs that responded quickly and favourably to a burn included three-flowered avens (*Geum triflorum*), milk vetch (*Astragalus striatus*), yarrow (*Achillea millefolium*), and pussytoes (*Antennaria nitida*). However, not all broad-leaved plants were favoured by burning. The lack of invasion by annual forbs in the first year was thought to be a result of a lack of seed source.

The fescue grassland is well adapted to fire and many of the perennial forbs and grasses recover quickly after burning, reducing effective competition from annuals. However, timing of

the burn is important to some species as a sharp reduction occurred in canopy coverage of slender wheatgrass (*Agropyron trachycaulum*), bearded wheatgrass (*A. subsecundum*) and rough fescue after a May 3 burn, when growth of these cool-season species was more advanced (Higgins et al. 1986). Best results were found if the burn is conducted as soon as possible after spring snow melt to minimize damage to rough fescue. Fall burning did not harm rough fescue but does leave the grassland exposed to possible frost damage during winter, and can be harmful to warm season grasses.

Grassland burns need to consider the timing of a burn in specific grassland types so as to occur when the species selected for enhancement are dormant. Generally, early spring burning, when the cool-season grasses are dormant, will benefit these species. Conversely, burning in the fall may adversely affect warm-season grasses such as western porcupine grass, which are still actively growing and completing seed production (Bailey 1978b).

In the aspen parkland of central Alberta, the effect of fire on a rough-fescue/western porcupine grass community was varied (Bailey 1978b). Herbage yields following spring or fall burning were not affected by the burn but there were significant changes in species composition. Spring burning caused a 25% to 60% decline in rough fescue cover while fall burning had a less detrimental effect. Western porcupine grass (*Stipa spartea* var. *curtiseta*) seed production was stimulated by spring burning and suppressed by fall burning. The cover of all shrubs was reduced by fire whereas many forbs increased (Bailey 1978b).

Aspen will either be enhanced or inhibited by fire, depending on the frequency of burns. Fire often kills the shoot portion of these poplars but may induce active regeneration from root suckers. Often, aspen abundance will exceed that of a pre-burn, after one event (Anderson and Bailey 1980). Due to the timing of food storage shortages, deciduous plants are most susceptible to serious damage in early to mid summer when carbohydrate levels are lowest. Burning in early spring before leaf-out or in autumn or winter when reserves are relatively low, may result in a vigorous sprouting response during the growing season.

Annual early spring burning in one area of central Alberta has been conducted over the past 25 to 30 years with the results of drastically reducing the cover of aspen and a reduction in shrub cover of 83% (Bailey 1978a). However, some shrub species, including snowberry, silverberry and Saskatoon were very tolerant of fire and increased or changed little in their frequency while decreasing in total cover. This indicates that unless prescribed reburning is continued, these species would eventually increase in response to fire.

Within the aspen parkland areas, the encroachment of aspen has reduced fescue grassland by about 75% (Bailey and Wroe 1974). Prescribed burning alone will suppress aspen, balsam and willows although periodic retreatment is required as tree regrowth is rapid and aspen suckers are 3 to 5 times as dense as the unburned forest in 3 to 4 years (Anderson and Bailey 1979).

The consensus of Bailey's (1978) work is that periodic carefully timed prescribed burning

can be used in the fescue grassland and aspen parkland to reduce litter build-up on ungrazed slopes. Reburning and heavy grazing or herbicide treatments are considered most effective in reducing shrub and tree cover, as one burn resulted in only a temporary set-back, and eventual increase. These prescribed burns were recommended to be done only during cycles of wet years.

Fire as a Tool for Grassland Reclamation and Management. One of the simplest and least expensive practices to improve poor quality grassland is prescribed burning, depending on the desired results and the existing conditions. Selective suppression or promotion of a particular plant species can be achieved by carefully timing the date of the fire in relation to the phenology of the particular species. Usually, those species actively growing when the area is burned are much more susceptible to injury and death than dormant species or those just initiating growth (Anderson et al. 1970).

The proper time to burn can be based on physiological stages (e.g., root reserves) or morphological stages (e.g., when buds are exposed), depending on the desired result. A sequence of fires may be necessary to restore grasslands to the desired condition. Safety factors and plant species responses will determine when to burn. All plants are most vulnerable during their active period of growth, when the plants' energy resources are lowest. As this varies among species, the burn needs to be tailored to the species of concern in the specific management objectives. Some grasses grow primarily in the cooler period of spring or fall (cool-season grasses) while others grow best during the heat of the summer (warm-season grasses). Timing of the burn can be managed to control these different groups.

Prescribed burning is not recommended during drought years as the recovery time of plants is hindered, and basal crowns and roots can be damaged when the soil is not moist, and the soil erosion hazard will also be increased (Trottier 1992). Nor is it recommended, generally, within the shortgrass prairie region or more xeric areas of the mixed grass prairie.

To maintain a healthy grassland, it is not likely that a burn should need to be conducted more often than once every 5 to 10 years, depending on the precipitation zone of the area. The drier the environment, the lower the frequency of burning required (Trottier 1992).

If exotic or woody invaders are to be controlled, one burn will not likely be adequate. Two or more carefully prescribed burns may be required in order to reduce the abundance of these plants. In the mixed and fescue prairie, earlier spring burns ensure that the dominant cool-season grasses are not damaged. One maintenance burn every 5 to 10 years is usually sufficient (Trottier 1992).

More recently fire has been used very successfully when combined with a clear understanding of the undesirable species to be controlled and how they react to specific burning, and which species one hopes to enhance. In one area of tall grass prairie, encroaching cool-season grass species were significantly reduced while the desired native warm-season grasses were enhanced by a prescribed burn set in early spring followed by late spring application of fertilizer and atrazine (Masters and Vogel 1988).

Anderson and Bailey (1979) concluded that the increased species diversity in burned areas was attributed to the reduction in competition from shrubs, higher light intensity at the soil surface, warmer soil temperatures, favourable seed bed, and release of nutrients. In another study, five years of repetitive spring burns significantly improved the structure, composition, and diversity of a severely degraded native prairie site, The procedure was most effective on sites where native prairie inclusions are large and well-dispersed within a large matrix of degraded sod dominated by brush or alien, cool-season grasses. If dispersion and quality of the native inclusions are poor, interplantings of native materials may greatly promote the recovery process (Becker 1988).

The use of fires in grassland reclamation following disturbances is not well documented and possibly has been under-utilized as a management/reclamation tool. The primary use of fire in the studies reviewed has been to reclaim grassland from encroaching forests and shrubs, and to improve rangeland for grazing purposes.

Reseeding of damaged sites is common, following soil conservation strategies, but these areas often do not return successfully back to a native state. Often the species selected for reseeding outcompete future colonization by native species. Perhaps, under careful circumstances, carefully planned prescribed burns, in combination with other methods, would be successful.

Methods of Prescribed Burning

Prescribed burning is risky and requires considerable operational experience and a knowledge of which species are present and how they will respond to the specific conditions of the burn. The weather conditions required for comparatively safe burning in the Alberta aspen parkland are presented in the following table (Bailey 1978).

Table. Weather Conditions Required for Successful Spring Burning in Central Alberta Aspen Parkland (Bailey 1978).

Vegetation Type	Minimum Temperature	Wind Speed	Maximum Number of Drying Days	Relative Humidity
Fescue grassland	7	3-20	65	1
Snowberry shrubland	13	3-20	50	4
Aspen forest	15	6-20	40	10
Aspen forest	18	12-25	30	14

Snow can be an advantage to spring burning programs in mesic areas of the Northern Great Plains. The grasslands melt free of snow several weeks before it has left the adjacent forests, acting as a fireguard. The greening grassland then acts as an effective fireguard when the forest is burned, several weeks later (Bailey 1978).

The trend toward prescribed burning of grasslands is increasing as knowledge of this

method and its safe application increases. Certain conditions, however, restrict its use:

1. fire behaviour or fire effects will not meet the objectives for the area under consideration;
2. if Federal or Provincial laws prohibit burning within the area;
3. local ordinances or zoning prohibit burning;
4. containment and safety factors are risky or questionable;
5. endangered species or natural communities may be subject to damage or their status is in doubt;

After a prescribed burn is started, with matches or sparkers, the firelines are spread with the drip torches or propane torches. There are basically three kinds of prescribed fires: Backing fires, which burn into the wind, move more slowly, burn hotter at the ground surface and are more easily controlled; Head fires, which burn with the wind, move faster, are less controlled and burn cooler at the ground surface; Flank fires, which burn at oblique angles to the wind direction and are a modification of backing fires. These are used to secure the flanks of a head fire as the head fire progresses.

There are about six commonly used patterns when implementing a prescribed grassland burn, each of which has specific applications depending on the site to be burned, its size and physical status, and the weather conditions.

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RECLAMATION RESEARCH REPORTS

1. **RRTAC 79-2: Proceedings: Workshop on Native Shrubs in Reclamation. P.F. Ziemkiewicz, C.A. Dermott and H.P. Sims (Editors). 104 pp. No longer available.**

The Workshop was organized as the first step in developing a Native Shrub reclamation research program. The Workshop provided a forum for the exchange of information and experiences on three topics: propagation; outplanting; and, species selection. Seven papers and the results of three discussion groups are presented.

2. **RRTAC 80-1: Test Plot Establishment: Native Grasses for Reclamation. R.S. Sadasivaiah and J. Weijer. 19 pp. No longer available.**

The report details the species used at three test plots in Alberta's Eastern Slopes (one at Caw Creek Ridge and two at Cadomin). Site preparation, experimental design, and planting method are also described.

3. **RRTAC 80-2: Alberta's Reclamation Research Program - 1979. Reclamation Research Technical Advisory Committee. 22 pp. No longer available.**

This report describes the expenditure of $1,190,006 of Alberta Heritage Savings Trust Fund monies on research under the Land Reclamation Program. The report outlines the objectives and research strategies of the four program areas, and describes the projects funded under each program.

4. **RRTAC 80-3: The Role of Organic Compounds in Salinization of Plains Coal Mining Sites. N.S.C. Cameron et al. 46 pp. No longer available.**

This is a literature review of the chemistry of sodic mine spoil and the changes expected to occur in groundwater.

5. **RRTAC 80-4: Proceedings: Workshop on Reconstruction of Forest Soils in Reclamation. P.F. Ziemkiewicz, S.K. Takyi and H.F. Regier (Editors). 160 pp. $10.00**

Experts in the field of forestry and forest soils report on research relevant to forest soil reconstruction and discuss the most effective means of restoring forestry capability of mined lands.

6. **RRTAC 80-5: Manual of Plant Species Suitability for Reclamation in Alberta. L.E. Watson, R.W. Parker and D.F. Polster. 2 vols, 541 pp. No longer available; replaced by RRTAC 89-4.**

Forty-three grass, fourteen forb, and thirty-four shrub and tree species are assessed in terms of their suitability for use in reclamation. Range maps, growth habit, propagation, tolerance, and availability information are provided.

7. **RRTAC 81-1: The Alberta Government's Reclamation Research Program - 1980. Reclamation Research Technical Advisory Committee. 25 pp. No longer available.**

This report describes the expenditure of $1,455,680 of Alberta Heritage Savings Trust Fund monies on research under the Land Reclamation Program. The report outlines the objectives and research strategies of the four program areas, and describes the projects funded under each program.

8. **RRTAC 81-2: 1980 Survey of Reclamation Activities in Alberta. D.G. Walker and R.L. Rothwell. 76 pp. $10.00**

This survey is an update of a report prepared in 1976 on reclamation activities in Alberta, and includes research and operational reclamation, locations, personnel, etc.

9. **RRTAC 81-3: Proceedings: Workshop on Coal Ash and Reclamation. P.F. Ziemkiewicz, R. Stein, R. Leitch and G. Lutwick (Editors). 253 pp. $10.00**

Presents nine technical papers on the chemical, physical, and engineering properties of Alberta fly and bottom ashes, revegetation of ash disposal sites, and use of ash as a soil amendment. Workshop discussions and summaries are also included.

10. **RRTAC 82-1: Land Surface Reclamation: An International Bibliography. H.P. Sims and C.B. Powter. 2 vols, 292 pp. $10.00**

Literature to 1980 pertinent to reclamation in Alberta is listed in Vol. 1 and is also on the University of Alberta computing system (in a SPIRES database called RECLAIM). Vol. 2 comprises the keyword index and computer access manual.

11. **RRTAC 82-2: A Bibliography of Baseline Studies in Alberta: Soils, Geology, Hydrology and Groundwater. C.B. Powter and H.P. Sims. 97 pp. $5.00**

This bibliography provides baseline information for persons involved in reclamation research or in the preparation of environmental impact assessments. Materials, up to date as of December 1981, are available in the Alberta Environment Library.

12. **RRTAC 82-3: The Alberta Government's Reclamation Research Program - 1981. Reclamation Research Technical Advisory Committee. 22 pp. No longer available.**

This report describes the expenditure of $1,499,525 of Alberta Heritage Savings Trust Fund monies on research under the Land Reclamation Program. The report outlines the objectives and research strategies of the four program areas, and describes the projects funded under each program.

13. **RRTAC 83-1: Soil Reconstruction Design for Reclamation of Oil Sand Tailings. Monenco Consultants Ltd. 185 pp. No longer available**

Volumes of peat and clay required to amend oil sand tailings were estimated based on existing literature. Separate soil prescriptions were made for spruce, jack pine, and herbaceous cover types. The estimates form the basis of field trials.

14. **RRTAC 83-2: The Alberta Government's Reclamation Research Program - 1982. Reclamation Research Technical Advisory Committee. 25 pp. No longer available.**

This report describes the expenditure of $1,536,142 of Alberta Heritage Savings Trust Fund monies on research under the Land Reclamation Program. The report outlines the objectives and research strategies of the four program areas, and describes the projects funded under each program.

15. **RRTAC 83-3: Evaluation of Pipeline Reclamation Practices on Agricultural Lands in Alberta. Hardy Associates (1978) Ltd. 205 pp. No longer available.**

Available information on pipeline reclamation practices was reviewed. A field survey was then conducted to determine the effects of pipe size, age, soil type, construction method, etc. on resulting crop production.

16. **RRTAC 83-4: Proceedings: Effects of Coal Mining on Eastern Slopes Hydrology. P.F. Ziemkiewicz (Editor). 123 pp. $10.00**

Technical papers are presented dealing with the impacts of mining on mountain watersheds, their flow characteristics, and resulting water quality. Mitigative measures and priorities were also discussed.

17. **RRTAC 83-5: Woody Plant Establishment and Management for Oil Sands Mine Reclamation. Techman Engineering Ltd. 124 pp. No longer available.**

This is a review and analysis of information on planting stock quality, rearing techniques, site preparation, planting, and procedures necessary to ensure survival of trees and shrubs in oil sand reclamation.

18. **RRTAC 84-1: Land Surface Reclamation: A Review of the International Literature. H.P. Sims, C.B. Powter and J.A. Campbell. 2 vols, 1549 pp. $20.00**

Nearly all topics of interest to reclamationists including mining methods, soil amendments, revegetation, propagation and toxic materials are reviewed in light of the international literature.

19. **RRTAC 84-2: Propagation Study: Use of Trees and Shrubs for Oil Sand Reclamation. Techman Engineering Ltd. 58 pp. $10.00**

This report evaluates and summarizes all available published and unpublished information on large-scale propagation methods for shrubs and trees to be used in oil sand reclamation.

20. **RRTAC 84-3: Reclamation Research Annual Report - 1983. P.F. Ziemkiewicz. 42 pp. $5.00**

This report details the Reclamation Research Program indicating priorities, descriptions of each research project, researchers, results, and expenditures.

21. **RRTAC 84-4: Soil Microbiology in Land Reclamation. D. Parkinson, R.M. Danielson, C. Griffiths, S. Visser and J.C. Zak. 2 vols, 676 pp. $10.00**

This is a collection of five reports dealing with re-establishment of fungal decomposers and mycorrhizal symbionts in various amended spoil types.

22. **RRTAC 85-1: Proceedings: Revegetation Methods for Alberta's Mountains and Foothills. P.F. Ziemkiewicz (Editor). 416 pp. No longer available.**

Results of long-term experiments and field experience on species selection, fertilization, reforestation, topsoiling, shrub propagation and establishment are presented.

23. **RRTAC 85-2: Reclamation Research Annual Report - 1984. P.F. Ziemkiewicz. 29 pp. $5.00**

This report details the Reclamation Research Program indicating priorities, descriptions of each research project, researchers, results, and expenditures.

24. **RRTAC 86-1: A Critical Analysis of Settling Pond Design and Alternative Technologies. A. Somani. 372 pp. $10.00**

The report examines the critical issue of settling pond design, and sizing and alternative technologies. The study was co-funded with The Coal Association of Canada.

25. **RRTAC 86-2: Characterization and Variability of Soil Reconstructed after Surface Mining in Central Alberta. T.M. Macyk. 146 pp. No longer available.**

Reconstructed soils representing different materials handling and replacement techniques were characterized, and variability in chemical and physical properties was assessed. The data obtained indicate that reconstructed soil properties are determined largely by parent material characteristics and further tempered by materials handling procedures. Mining tends to create a relatively homogeneous soil landscape in contrast to the mixture of diverse soils found before mining.

26. **RRTAC 86-3: Generalized Procedures for Assessing Post-Mining Groundwater Supply Potential in the Plains of Alberta - Plains Hydrology and Reclamation Project. M.R. Trudell and S.R. Moran. 30 pp. $5.00**

In the Plains region of Alberta, the surface mining of coal generally occurs in rural, agricultural areas in which domestic water supply requirements are met almost entirely by groundwater. Consequently, an important aspect of the capability of reclaimed lands to satisfy the needs of a residential component is the post-mining availability of groundwater. This report proposes a sequence of steps or procedures to identify and characterize potential post-mining aquifers.

27. **RRTAC 86-4: Geology of the Battle River Site: Plains Hydrology and Reclamation Project. A. Maslowski-Schutze, R. Li, M. Fenton and S.R. Moran. 86 pp. $10.00**

This report summarizes the geological setting of the Battle River study site. It is designed to provide a general understanding of geological conditions adequate to establish a framework for hydrogeological and general reclamation studies. The report is not intended to be a detailed synthesis such as would be required for mine planning purposes.

28. **RRTAC 86-5: Chemical and Mineralogical Properties of Overburden: Plains Hydrology and Reclamation Project. A. Maslowski-Schutze. 71 pp. $10.00**

This report describes the physical and mineralogical properties of overburden materials in an effort to identify individual beds within the bedrock overburden that might be significantly different in terms of reclamation potential.

29. **RRTAC 86-6: Post-Mining Groundwater Supply at the Battle River Site: Plains Hydrology and Reclamation Project. M.R. Trudell, G.J. Sterenberg and S.R. Moran. 49 pp. $5.00**

The report deals with the availability of water supply in or beneath cast overburden to support post-mining land use, including both quantity and quality considerations. The study area is in the Battle River Mining area in east-central Alberta.

30. **RRTAC 86-7: Post-Mining Groundwater Supply at the Highvale Site: Plains Hydrology and Reclamation Project. M.R. Trudell. 25 pp. $5.00**

This report evaluates the availability of water supply in or beneath cast overburden to support post-mining land use, including both quantity and quality considerations. The study area is the Highvale mining area in west-central Alberta.

31. **RRTAC 86-8: Reclamation Research Annual Report - 1985. P.F. Ziemkiewicz. 54 pp. $5.00**

This report details the Reclamation Research Program indicating priorities, descriptions of each research project, researchers, results, and expenditures.

32. **RRTAC 86-9: Wildlife Habitat Requirements and Reclamation Techniques for the Mountains and Foothills of Alberta. J.E. Green, R.E. Salter and D.G. Walker. 285 pp. No longer available.**

This report presents a review of relevant North American literature on wildlife habitats in mountain and foothills biomes, reclamation techniques, potential problems in wildlife habitat reclamation, and potential habitat assessment methodologies. Four biomes (Alpine, Subalpine, Montane, and Boreal Uplands) and 10 key wildlife species (snowshoe hare, beaver, muskrat, elk, moose, caribou, mountain goat, bighorn sheep, spruce grouse, and white-tailed ptarmigan) are discussed. The study was co-funded with The Coal Association of Canada.

33. **RRTAC 87-1: Disposal of Drilling Wastes. L.A. Leskiw, E. Reinl-Dwyer, T.L. Dabrowski, B.J. Rutherford and H. Hamilton. 210 pp. No longer available.**

Current drilling waste disposal practices are reviewed and criteria in Alberta guidelines are assessed. The report also identifies research needs and indicates mitigation measures. A manual provides a decision-making flowchart to assist in selecting methods of environmentally safe waste disposal.

34. **RRTAC 87-2: Minesoil and Landscape Reclamation of the Coal Mines in Alberta's Mountains and Foothills. A.W. Fedkenheuer, L.J. Knapik and D.G. Walker. 174 pp. No longer available.**

This report reviews current reclamation practices with regard to site and soil reconstruction and re-establishment of biological productivity. It also identifies research needs in the Mountain-Foothills area. The study was co-funded with The Coal Association of Canada.

35. **RRTAC 87-3: Gel and Saline Drilling Wastes in Alberta: Workshop Proceedings. D.A. Lloyd (Compiler). 218 pp. No longer available.**

Technical papers were presented which describe: mud systems used and their purpose; industrial constraints; government regulations, procedures and concerns; environmental considerations in waste disposal; and toxic constituents of drilling wastes. Answers to a questionnaire distributed to participants are included in an appendix.

36. **RRTAC 87-4: Reclamation Research Annual Report - 1986. 50 pp. No longer available.**

This report details the Reclamation Research Program indicating priorities, descriptions of each research project, researchers, results, and expenditures.

37. **RRTAC 87-5: Review of the Scientific Basis of Water Quality Criteria for the East Slope Foothills of Alberta. Beak Associates Consulting Ltd. 46 pp. $10.00**

The report reviews existing Alberta guidelines to assess the quality of water drained from coal mine sites in the East Slope Foothills of Alberta. World literature was reviewed within the context of the East Slopes environment and current mining operations. The ability of coal mine operators to meet the various guidelines is discussed. The study was co-funded with The Coal Association of Canada.

38. **RRTAC 87-6: Assessing Design Flows and Sediment Discharge on the Eastern Slopes. Hydrocon Engineering (Continental) Ltd. and Monenco Consultants Ltd. 97 pp. $10.00**

The report provides an evaluation of current methodologies used to determine sediment yields due to rainfall events in well-defined areas. Models are available in Alberta to evaluate water and sediment discharge in a post-mining situation. SEDIMOT II (Sedimentology Disturbed Modelling Techniques) is a single storm model that was developed specifically for the design of sediment control structures in watersheds disturbed by surface mining and is well suited to Alberta conditions. The study was co-funded with The Coal Association of Canada.

39. **RRTAC 87-7: The Use of Bottom Ash as an Amendment to Sodic Spoil. S. Fullerton. 83 pp. No longer available.**

The report details the use of bottom ash as an amendment to sodic coal mine spoil. Several rates and methods of application of bottom ash to sodic spoil were tested to determine which was the best at reducing the effects of excess sodium and promoting crop growth. Field trials were set up near the Vesta mine in East Central Alberta using ash readily available from a nearby coal-fired thermal generating station. The research indicated that bottom ash incorporated to a depth of 30 cm using a subsoiler provided the best results.

40. **RRTAC 87-8: Waste Dump Design for Erosion Control. R.G. Chopiuk and S.E. Thornton. 45 pp. $5.00**

This report describes a study to evaluate the potential influence of erosion from reclaimed waste dumps on downslope environments such as streams and rivers. Sites were selected from coal mines in Alberta's mountains and foothills, and included resloped dumps of different configurations and ages, and having different vegetation covers. The study concluded that the average annual amount of surface erosion is minimal. As expected, erosion was greatest on slopes which were newly regraded. Slopes with dense grass cover showed no signs of erosion. Generally, the amount of erosion decreased with time, as a result of initial loss of fine particles, the formation of a weathered surface, and increased vegetative cover.

41. **RRTAC 87-9: Hydrogeology and Groundwater Chemistry of the Battle River Mining Area. M.R. Trudell, R.L. Faught and S.R. Moran. 97 pp. No longer available.**

This report describes the premining geologic conditions in the Battle River coal mining area including the geology as well as the groundwater flow patterns, and the groundwater quality of a sequence of several water-bearing formations extending from the surface to a depth of about 100 metres.

42. **RRTAC 87-10: Soil Survey of the Plains Hydrology and Reclamation Project - Battle River Project Area. T.M. Macyk and A.H. MacLean. 62 pp. plus 8 maps. $10.00**

The report evaluates the capability of post-mining landscapes and assesses the changes in capability as a result of mining, in the Battle River mining area. Detailed soils information is provided in the report for lands adjacent to areas already mined as well as for lands that are destined to be mined. Characterization of the reconstructed soils in the reclaimed areas is also provided. Data were collected from 1979 to 1985. Eight maps supplement the report.

43. **RRTAC 87-11: Geology of the Highvale Study Site: Plains Hydrology and Reclamation Project. A. Maslowski-Schutze. 78 pp. $10.00**

The report is one of a series that describes the geology, soils and groundwater conditions at the Highvale Coal Mine study site. The purpose of the study was to establish a summary of site geology to a level of detail necessary to provide a framework for studies of hydrogeology and reclamation.

44. **RRTAC 87-12: Premining Groundwater Conditions at the Highvale Site. M.R. Trudell and R. Faught. 83 pp. $10.00**

This report presents a detailed discussion of the premining flow patterns, hydraulic properties, and isotopic and hydrochemical characteristics of five layers within the Paskapoo Geological Formation, the underlying sandstone beds of the Upper Horseshoe Canyon Formation, and the surficial glacial drift.

45. **RRTAC 87-13: An Agricultural Capability Rating System for Reconstructed Soils. T.M. Macyk. 27 pp. $5.00**

This report provides the rationale and a system for assessing the agricultural capability of reconstructed soils. Data on the properties of the soils used in this report are provided in RRTAC 86-2.

46. **RRTAC 88-1: A Proposed Evaluation System for Wildlife Habitat Reclamation in the Mountains and Foothills Biomes of Alberta: Proposed Methodology and Assessment Handbook. T.R. Eccles, R.E. Salter and J.E. Green. 101 pp. plus appendix. $10.00**

The report focuses on the development of guidelines and procedures for the assessment of reclaimed wildlife habitat in the Mountains and Foothills regions of Alberta. The technical section provides background documentation including a discussion of reclamation planning, a listing of reclamation habitats and associated key wildlife species, conditions required for development, recommended revegetation species, suitable reclamation techniques, a description of the recommended assessment techniques and a glossary of basic terminology. The assessment handbook section contains basic information necessary for evaluating wildlife habitat reclamation, including assessment scoresheets for 15 different reclamation habitats, standard methodologies for measuring habitat variables used as assessment criteria, and minimum requirements for certification. This handbook is intended as a field manual that could potentially be used by site operators and reclamation officers. The study was co-funded with The Coal Association of Canada.

47. **RRTAC 88-2: Plains Hydrology and Reclamation Project: Spoil Groundwater Chemistry and its Impacts on Surface Water. M.R. Trudell (Compiler). 135 pp. $10.00**

Two reports comprise this volume. The first "Chemistry of Groundwater in Mine Spoil, Central Alberta," describes the chemical make-up of spoil groundwater at four mines in the Plains of Alberta. It explains the nature and magnitude of changes in groundwater chemistry following mining and reclamation. The second report, "Impacts of Surface Mining on Chemical Quality of Streams in the Battle River Mining Area," describes the chemical quality of water in streams in the Battle River mining area, and the potential impact of groundwater discharge from surface mines on these streams.

48. **RRTAC 88-3: Revegetation of Oil Sands Tailings: Growth Improvement of Silver-berry and Buffalo-berry by Inoculation with Mycorrhizal Fungi and N_2-Fixing Bacteria. S. Visser and R.M. Danielson. 98 pp. $10.00**

The report provides results of a study: (1) To determine the mycorrhizal affinities of various actinorrhizal shrubs in the Fort McMurray, Alberta region; (2) To establish a basis for justifying symbiont inoculation of buffalo-berry and silver-berry; (3) To develop a growing regime for the greenhouse production of mycorrhizal, nodulated silver-berry and buffalo-berry; and, (4) To conduct a field trial on reconstructed soil on the Syncrude Canada Limited oil sands site to critically evaluate the growth performance of inoculated silver-berry and buffalo-berry as compared with their un-inoculated counterparts.

49. **RRTAC 88-4: Plains Hydrology and Reclamation Project: Investigation of the Settlement Behaviour of Mine Backfill. D.R. Pauls (compiler). 135 pp. $10.00**

This three part volume covers the laboratory assessment of the potential for subsidence in reclaimed landscapes. The first report in this volume, "Simulation of Mine Spoil Subsidence by Consolidation Tests," covers laboratory simulations of the subsidence process particularly as it is influenced by resaturation of mine spoil. The second report, "Water Sensitivity of Smectitic Overburden: Plains Region of Alberta," describes a series of laboratory tests to determine the behaviour of overburden materials when brought into contact with water. The report entitled "Classification System for Transitional Materials: Plains Region of Alberta," describes a lithological classification system developed to address the characteristics of the smectite rich, clayey transition materials that make up the overburden in the Plains of Alberta.

50. **RRTAC 88-5: Ectomycorrhizae of Jack Pine and Green Alder: Assessment of the Need for Inoculation, Development of Inoculation Techniques and Outplanting Trials on Oil Sand Tailings. R.M. Danielson and S. Visser. 177 pp. $10.00**

The overall objective of this research was to characterize the mycorrhizal status of Jack Pine and Green Alder which are prime candidates as reclamation species for oil sand tailings and to determine the potential benefits of mycorrhizae on plant performance. This entailed determining the symbiont status of container-grown nursery stock and the quantity and quality of inoculum in reconstructed soils, developing inoculation techniques and finally, performance testing in an actual reclamation setting.

51. **RRTAC 88-6: Reclamation Research Annual Report - 1987. Reclamation Research Technical Advisory Committee. 67 pp. No longer available.**

This annual report describes the expenditure of $500,000.00 of Alberta Heritage Savings Trust Fund monies on research under the Land Reclamation Program. The report outlines the objectives and research strategies of the four program areas, and describes the projects funded under each program.

52. **RRTAC 88-7: Baseline Growth Performance Levels and Assessment Procedure for Commercial Tree Species in Alberta's Mountains and Foothills. W.R. Dempster and Associates Ltd. 66 pp. $5.00**

Data on juvenile height development of lodgepole pine and white spruce from cut-over or burned sites in the Eastern Slopes of Alberta were used to define reasonable expectations of early growth performance as a basis for evaluating the success of reforestation following coal mining. Equations were developed predicting total seedling height and current annual height increment as a function of age and elevation. Procedures are described for applying the equations, with further adjustments for drainage class and aspect, to develop local growth performance against these expectations. The study was co-funded with The Coal Association of Canada.

53. **RRTAC 88-8: Alberta Forest Service Watershed Management Field and Laboratory Methods. A.M.K. Nip and R.A. Hursey. 4 Sections, various pagings. $10.00**

Disturbances such as coal mines in the Eastern Slopes of Alberta have the potential for affecting watershed quality during and following mining. The collection of hydrometric, water quality and hydrometeorologic information is a complex task. A variety of instruments and measurement methods are required to produce a record of hydrologic inputs and outputs for a watershed basin. There is a growing awareness and recognition that standardization of data acquisition methods is required to ensure data comparability, and to allow comparison of data analyses. The purpose of this manual is to assist those involved in the field of data acquisition by outlining methods, practices and instruments which are reliable and recognized by the International Organization for Standardization.

54. **RRTAC 88-9: Computer Analysis of the Factors Influencing Groundwater Flow and Mass Transport in a System Disturbed by Strip Mining. F.W. Schwartz and A.S. Crowe. 78 pp. No longer available.**

Work presented in this report demonstrates how a groundwater flow model can be used to study a variety of mining-related problems such as declining water levels in areas around the mine as a result of dewatering, and the development of high water tables in spoil once resaturation is complete. This report investigates the role of various hydrogeological parameters that influence the magnitude, timing, and extent of water level changes during and following mining at the regional scale. The modelling approach described here represents a major advance on existing work.

55. **RRTAC 88-10: Review of Literature Related to Clay Liners for Sump Disposal of Drilling Wastes. D.R. Pauls, S.R. Moran and T. Macyk. 61 pp. No longer available.**

The report reviews and analyses the effectiveness of geological containment of drilling waste in sumps. Of particular importance was the determination of changes in properties of clay materials as a result of contact with highly saline brines containing various organic chemicals.

56. **RRTAC 88-11: Highvale Soil Reconstruction Project: Five Year Summary. D.N. Graveland, T.A. Oddie, A.E. Osborne and L.A. Panek. 104 pp. $10.00**

This report provides details of a five year study to determine a suitable thickness of subsoil to replace over minespoil in the Highvale plains coal mine area to ensure return of agricultural capability. The study also examined the effect of slope and aspect on agricultural capability. This study was funded and managed with industry assistance.

57. **RRTAC 88-12: A Review of the International Literature on Mine Spoil Subsidence. J.D. Scott, G. Zinter, D.R. Pauls and M.B. Dusseault. 36 pp. $10.00**

The report reviews available engineering literature relative to subsidence of reclaimed mine spoil. The report covers methods for site investigation, field monitoring programs and lab programs, mechanisms of settlement, and remedial measures.

58. **RRTAC 89-1: Reclamation Research Annual Report - 1988. 74 pp. $5.00**

This annual report describes the expenditure of $280,000.00 of Alberta Heritage Savings Trust Fund monies on research under the Land Reclamation Program. The report outlines the objectives and research strategies of the four program areas, and describes the projects funded under each program.

59. **RRTAC 89-2: Proceedings of the Conference: Reclamation, A Global Perspective. D.G. Walker, C.B. Powter and M.W. Pole (Compilers). 2 Vols., 854 pp. No longer available.**

Over 250 delegates from all over the world attended this conference held in Calgary in August, 1989. The proceedings contains over 85 peer-reviewed papers under the following headings: A Global Perspective; Northern and High Altitude Reclamation; Fish & Wildlife and Rangeland Reclamation; Water; Herbaceous Revegetation; Woody Plant Revegetation and Succession; Industrial and Urban Sites; Problems and Solutions; Sodic and Saline Materials; Soils and Overburden; Acid Generating Materials; and, Mine Tailings.

60. **RRTAC 89-3: Efficiency of Activated Charcoal for Inactivation of Bromacil and Tebuthiuron Residues in Soil. M.P. Sharma. 38 pp. ISBN 0-7732-0878-X. $5.00**

Bromacil and Tebuthiuron were commonly used soil sterilants on well sites, battery sites and other industrial sites in Alberta where total vegetation control was desired. Activated charcoal was found to be effective in binding the sterilants in greenhouse trials. The influence of factors such as herbicide:charcoal concentration ratio, soil texture, organic matter content, soil moisture, and the time interval between charcoal incorporation and plant establishment were evaluated in the greenhouse.

61. **RRTAC 89-4: Manual of Plant Species Suitability for Reclamation in Alberta - 2nd Edition. Hardy BBT Limited. 436 pp. ISBN 0-7732-0882-8. $10.00.**

This is an updated version of RRTAC Report 80-5 which describes the characteristics of 43 grass, 14 forb and 34 shrub and tree species which make them suitable for reclamation in Alberta. The report has been updated in several important ways: a line drawing of each species has been added; the range maps for each species have been redrawn based on an ecosystem classification of the province; new information (to 1990) has been added, particularly in the sections on reclamation use; and the material has been reorganized to facilitate information retrieval. Of greatest interest is the performance chart that precedes each species and the combined performance charts for the grass, forb, and shrub/tree groups. These allow the reader to pick out at a glance species that may suit their particular needs. The report was produced with the assistance of a grant from the Recreation, Parks and Wildlife Foundation.

62. **RRTAC 89-5: Battle River Soil Reconstruction Project Five Year Summary. L.A. Leskiw. 188 pp. $10.00**

This report summarizes the results of a five year study to investigate methods required to return capability to land surface mined for coal in the Battle River area of central Alberta. Studies were conducted on: the amounts of subsoil required, the potential of gypsum and bottom ash to amend adverse soil properties, and the effects of slope angle and aspect. Forage and cereal crop growth was evaluated, as were changes in soil chemistry, density and moisture holding characteristics.

63. **RRTAC 89-6: Detailed Sampling, Characterization and Greenhouse Pot Trials Relative to Drilling Wastes in Alberta. T.M. Macyk, F.I. Nikiforuk, S.A. Abboud and Z.W. Widtman. 228 pp. No longer available.**

This report summarizes a three-year study of the chemistry of freshwater gel, KCl, NaCl, DAP, and invert drilling wastes, both solids and liquids, from three regions in Alberta: Cold Lake, Eastern Slopes, and Peace River/Grande Prairie. A greenhouse study also examined the effects of adding various amounts of waste to soil on grass growth and soil chemistry. Methods for sampling drilling wastes are recommended.

64. **RRTAC 89-7: A User's Guide for the Prediction of Post-Mining Groundwater Chemistry from Overburden Characteristics. M.R. Trudell and D.C. Cheel. 55 pp. $5.00**

This report provides the detailed procedure and methodology that is required to produce a prediction of post-mining groundwater chemistry for plains coal mines, based on the soluble salt characteristics of overburden materials. The fundamental component of the prediction procedure is the geochemical model PHREEQE, developed by the U.S. Geological Survey, which is in the public domain and has been adapted for use on personal computers.

65. **RRTAC 90-1: Reclamation Research Annual Report - 1989. 62 pp. No longer available.**

This annual report describes the expenditure of $480,000.00 of Alberta Heritage Savings Trust Fund monies on research under the Land Reclamation Program. The report outlines the objectives and research strategies of the four program areas, and describes the projects funded under each program.

66. **RRTAC 90-2: Initial Selection for Salt Tolerance in Rocky Mountain Accessions of Slender Wheatgrass and Alpine Bluegrass. R. Hermesh, J. Woosaree, B.A. Darroch, S.N. Acharya and A. Smreciu. 40 pp. $5.00**

Selected lines of slender wheatgrass and alpine bluegrass collected from alpine and subalpine regions of Alberta as part of another native grass project were evaluated for their ability to emerge in a saline medium. Eleven slender wheatgrass and 72 alpine bluegrass lines had a higher percentage emergence than the Orbit Tall Wheatgrass control (a commonly available commercial grass). This means that as well as an ability to grow in high elevation areas, these lines may also be suitable for use in areas where saline soil conditions are present. Thus, their usefulness for reclamation has expanded.

67. **RRTAC 90-3: Natural Plant Invasion into Reclaimed Oil Sands Mine Sites. Hardy BBT Limited. 65 pp. $5.00**

Vegetation data from reclaimed sites on the Syncrude and Suncor oil sands mines have been summarized and related to site and factors and reclamation methods. Natural invasion into sites seeded to agronomic grasses and legumes was minimal even after 15 years. Invasion was slightly greater in sites seeded to native species, but was greatest on sites that were not seeded. Invasion was mostly from agronomic species and native forbs; native shrub and tree invasion was minimal.

68. **RRTAC 90-4: Physical and Hydrological Characteristics of Ponds in Reclaimed Upland Landscape Settings and their Impact on Agricultural Capability. S.R. Moran, T.M. Macyk, M.R. Trudell and M.E. Pigot, Alberta Research Council. 76 pp. $5.00**

The report details the results and conclusions from studying a pond in a reclaimed upland site in Vesta Mine. The pond formed as a result of two factors: (1) a berm which channelled meltwater into a series of subsidence depressions, forming a closed basin; and (2) low hydraulic conductivity in the lower subsoil and upper spoil as a result of compaction during placement and grading which did not allow for rapid drainage of ponded water. Ponds such as this in the reclaimed landscape can affect agricultural capability by: (1) reducing the amount of farmable land (however, the area covered by these ponds in this region is less than half of that found in unmined areas); and, (2) creating the conditions necessary for the progressive development of saline and potentially sodic soils in the area adjacent to the pond.

69. **RRTAC 90-5: Review of the Effects of Storage on Topsoil Quality. Thurber Consultants Ltd., Land Resources Network Ltd., and Norwest Soil Research Ltd. 116 pp. $10.00**

The international literature was reviewed to determine the potential effects of storage on topsoil quality. Conclusions from the review indicated that storage does not appear to have any severe and longterm effects on topsoil quality. Chemical changes may be rectified with the use of fertilizers or manure. Physical changes appear to be potentially less serious than changes in soil quality associated with the stripping and respreading operations. Soil biotic populations appear to revert to pre-disturbance levels of activity within acceptable timeframes. Broad, shallow storage piles that are seeded to acceptable grass and legume species are recommended; agrochemical use should be carefully controlled to ensure soil biota are not destroyed.

70. **RRTAC 90-6: Proceedings of the Industry/Government Three-Lift Soils Handling Workshop. Deloitte & Touche. 168 pp. $10.00**

This report documents the results of a two-day workshop on the issue of three-lift soils handling for pipelines. The workshop was organized and funded by RRTAC, the Canadian Petroleum Association and the Independent Petroleum Association of Canada. Day one focused on presentation of government and industry views on the criteria for three-lift, the rationale and field data in support of three- and two-lift procedures, and an examination of the various soil handling methods in use. During day two, five working groups discussed four issues: alternatives to three-lift; interim criteria and suggested revisions; research needs; definitions of terms. The results of the workshop are being used by a government/industry committee to revise soils handling criteria for pipelines.

71. **RRTAC 90-7: Reclamation of Disturbed Alpine Lands: A Literature Review. Hardy BBT Limited. 209 pp. $10.00**

This review covers current information from North American sources on measures needed to reclaim alpine disturbances. The review provides information on pertinent Acts and regulations with respect to development and environmental protection of alpine areas. It also discusses: alpine environmental conditions; current disturbances to alpine areas; reclamation planning; site and surface preparation; revegetation; and, fertilization. The report also provides a list of research and information needs for alpine reclamation in Alberta.

72. **RRTAC 90-8: Plains Hydrology and Reclamation Project: Summary Report. S.R. Moran, M.R. Trudell, T.M. Macyk and D.B. Cheel. 105 pp. $10.00**

This report summarizes a 10-year study on the interactions of groundwater, soils and geology as they affect successful reclamation of surface coal mines in the plains of Alberta. The report covers: Characterization of the Battle River and Wabamun study areas; Properties of reclaimed materials and landscapes; Impacts of mining and reclamation on post-mining land use; and, Implications for reclamation practice and regulation. This project has led to the publication of 18 RRTAC reports and 22 papers in conference proceedings and referred journals.

73. **RRTAC 90-9: Literature Review on the Disposal of Drilling Waste Solids. Monenco Consultants Limited. 83 pp. $5.00**

This report reviews the literature on, and government and industry experience with, burial of drilling waste solids in an Alberta context. The review covers current regulations in Alberta, other provinces, various states in the US and other countries. Definitions of various types of burial are provided, as well as brief summaries of other possible disposal methods. Environmental concerns with the various options are presented as well as limited information on costs and monitoring of burial sites. The main conclusion of the work is that burial is still a viable option for some waste types but that each site and waste type must be evaluated on its own merits.

74. **RRTAC 90-10: Potential Contamination of Shallow Aquifers by Surface Mining of Coal. M.R. Trudell, S.R. Moran and T.M. Macyk. 75 pp. $5.00**

This report presents the results of a field investigation of the movement of salinized groundwater from a mined and reclaimed coal mine near Forestburg into an adjacent unmined area. The movement is considered to be an unusual occurrence resulting from a combination of a hydraulic head that is higher in the mined area than in the adjacent coal aquifer, and the presence of a thin surficial sand aquifer adjacent to the mine. The high hydraulic head results from deep ponds in the reclaimed landscape that recharge the base of the spoil.

75. **RRTAC 91-1: Reclamation Research Annual Report - 1990. Reclamation Research Technical Advisory Committee. 69 pp. No longer available.**

This annual report describes the expenditure of $499 612 of Alberta Heritage Savings Trust Fund monies on research under the Land Reclamation Program. The report outlines the objectives and research strategies of the four program areas, and describes the projects funded under each program. The report lists the 70 research reports published under the program.

76. **RRTAC 91-2: Winter Soil Evaluation and Mapping for Regulated Pipelines. A.G. Twardy. 43 pp. ISBN 0-7732-0874-7. $5.00**

Where possible, summer soil evaluations are preferred for pipelines. However, when winter soil evaluations must be done, this report lays out the constraints and requirements for obtaining the best possible information. Specific recommendations include: restricting evaluations to the time of day with the best light conditions; use of core- or auger-equipped drill-trucks; increased frequency of site inspections and soil analyses; and, hiring a well-qualified pedologist. The province's soils are divided into four classes, based on their difficulty of evaluation in winter: slight (most soils); moderate; high; and, severe (salt-affected soils in the Brown and Dark Brown Soil Zones).

77. **RRTAC 91-3: A User Guide to Pit and Quarry Reclamation in Alberta. J.E. Green, T.D. Van Egmond, C. Wylie, I. Jones, L. Knapik and L.R. Paterson. 151 pp. ISBN 0-7732-0876-3. $10.00**

Sand and gravel pits or quarries are usually reclaimed to the original land use, especially if that was better quality agricultural or forested land. However, there are times when alternative land uses are possible. This report outlines some of the alternate land uses for reclaimed sand and gravel pits or quarries, including: agriculture, forestry, wildlife habitat, fish habitat, recreation, and residential and industrial use. The report provides a general introduction to the industry and to the reclamation process, and then outlines some of the factors to consider in selecting a land use and the methods for reclamation. The report is <u>not</u> a detailed guide to reclamation; it is intended to help an operator determine if a land use would be suitable and to guide him or her to other sources of information.

78. **RRTAC 91-4: Soil Physical Properties in Reclamation. M.A. Naeth, D.J. White, D.S. Chanasyk, T.M. Macyk, C.B. Powter and D.J. Thacker. 204 pp. ISBN 0-7732-0880-1. $10.00**

This report provides information from the literature and Alberta sources on a variety of soil physical properties that can be measured on reclaimed sites. Each property is explained, measurement methods, problems, level of accuracy and common soil values are presented, and methods of dealing with the property (prevention, alleviation) are discussed. The report also contains the results of a workshop held to discuss soil physical properties and the state-of-the-art in Alberta.

79. **RRTAC 92-1: Reclamation of Sterilant Affected Sites: A Review of the Issue in Alberta. M. Cotton and M.P. Sharma. 64 pp. ISBN 0-7732-0884-4. $5.00**

This report assesses the extent of sterilant use on oil and gas leases in Alberta, identifies some of the concerns related to reclamation of sterilant affected sites and the common methods for reclaiming these sites, and outlines the methods for sampling and analyzing soils from sterilant affected sites. The report also provides an outline of a research program to address issues raised by government and industry staff.

80. **RRTAC 92-2: Reclamation Research Annual Report - 1991. Reclamation Research Technical Advisory Committee. 55 pp. ISBN 0-7732-0888-7. No longer available.**

This report describes the expenditure of $485,065 of Alberta Heritage Savings Trust Fund monies on research under the Land Reclamation Program. The report outlines the objectives and research strategies of the five program areas, and describes the projects funded under each program. It also lists the 75 research reports that have been published to date.

81. **RRTAC 92-3: Proceedings of the Industry/Government Pipeline Reclamation Success Measurement Workshop. R.J. Mahnic and J.A. Toogood. 62 pp. ISBN 0-7732-0886-0. $5.00.**

This report presents the results of a workshop to identify the soil and vegetation parameters that should be used to assess reclamation success on pipelines in Alberta. Six soil parameters (topsoil admixing; topsoil replacement thickness; compaction; soil loss by erosion; texture; and salinity) and six vegetation parameters (plant density; species composition; ground cover; vigour; weeds/undesirable species; and rooting characteristics) were selected as most important. Working groups discussed these parameters and presented suggested methods for assessing them in the field.

82. **RRTAC 92-4: Oil Sands Soil Reconstruction Project Five Year Summary. HBT AGRA Limited. 109 pp. ISBN 0-7732-0875-5. $10.00**

This report documents a five year study of the effects of clay and peat amendments to oil sand tailings sand on survival and growth of trees and shrubs. Ten species (jack pine, white spruce, serviceberry, silverberry, buffaloberry, pin cherry, prickly/woods rose, Northwest poplar, green alder, and Bebb willow) were planted into tailings sand amended with three levels of peat and three levels of clay. The treatments were incorporated to a depth of 20 cm or 40 cm. Data are provided on plant survival and growth, root size and distribution, disease and small mammal damage, herbaceous cover, soil moisture, soil chemistry, and bulk density.

83. **RRTAC 92-5: A Computer Program to Simulate Groundwater Flow and Contaminant Transport in the Vicinity of Active and Reclaimed Strip Mines: A User's Guide. A.S. Crowe and F.W. Schwartz, SIMCO Groundwater Research Ltd. 104 pp. plus appendix. ISBN 0-7732-0877-1. NOTE: This report is only available from the Alberta Research Council as ARC Information Series 119. $20.00**

The manual describes a computer program that was developed to study the influence of coal strip mining on groundwater flow systems and to simulate the transport of generated contaminants, both spatially and in time, in the vicinity of a mine. All three phases of a strip mine can be simulated: the pre-mining regional groundwater flow system; the mining and reclamation phase; and, the post-mining water level readjustment phase. The model is sufficiently general to enable the user to specify virtually any type of geological conditions, mining scenario, and boundary conditions.

84. **RRTAC 92-6: Alberta Drilling Waste Sump Chemistry Study. Volume I: Report (Volume II: Appendices is only available through the Alberta Research Council). T.M. Macyk, S.A. Abboud and F.I. Nikiforuk, Alberta Research Council. 217 pp. ISBN 0-7732-0879-8. $10.00.**

This study synthesizes the data from sampling and analysis of the solids and liquids found in 128 drilling waste sumps across Alberta. Drilling waste types sampled included: 72 freshwater gel, 19 invert, 27 KCl, 2 NaCl, and 8 others. Data and statistics are tabulated by waste type, depth of the drill hole, and ERCB administrative region for both the solids and the liquids. Using preliminary loading limits developed by the government/industry Drilling Waste Review Committee, the report presents information on the volume and depth of waste that could be landspread, and the area required for landspreading. The oil and gas industry provided approximately $585,000 for the sampling and analysis phase of this study.

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